Hand Book of PIPE

East Jersey Pipe Co.

Handbook of Pipe

COMPRISING tables, charts and other useful information relating to the subject of the carrying of fluids and gases by pipe; pipe installation and test data. More particularly that having to do with large diameter steel pipe together with the story of "LOCK-BAR" and Riveted Steel pipe as manufactured by—

The East Jersey Pipe Company

New York, N. Y.

1920

THE EAST JERSEY PIPE COMPANY

New York, N. Y.

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PREFACE

THE increased demand for additional water, gas and oil pipe lines throughout the country, together with the apparent need for an engineering exposition of the subject of steel pipe, which will be useful to Engineers, has caused the Company to depart from its usual practice of merely cataloging briefly the merits of the products it manufactures and to issue in convenient form, for the man in the field as well as the man in the office, this "Handbook of Pipe."

Certain subjects closely related to the use of pipe have been incorporated herein, and also such general information and engineering data as is germane to the subject. In the compilation of the engineering data, the work of only competent authorities has been resorted to and wherever use has been made of such material, due credit has been given.

It is hoped that the "Handbook" may be of as much service to those receiving it, as the measure of pleasure which the Company derives in presenting it, with its compliments.

THE EAST JERSEY PIPE COMPANY

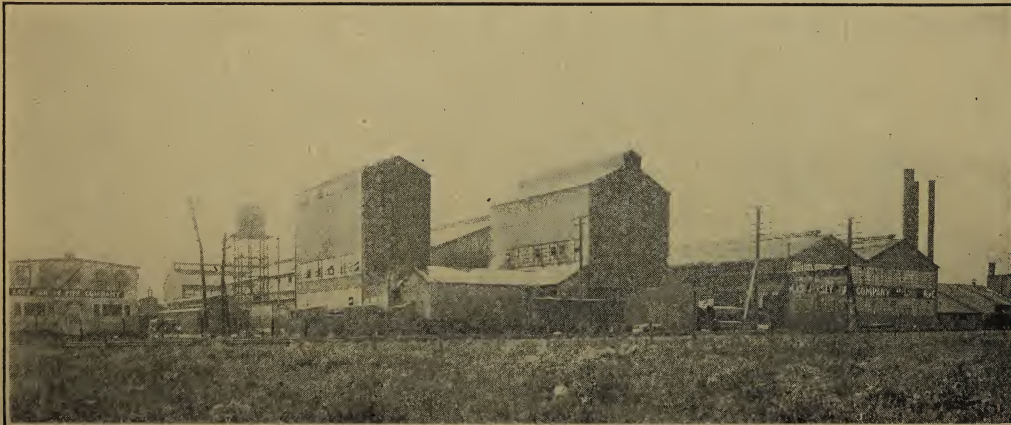


Fig. 1—THE WORKS OF THE EAST JERSEY PIPE CO., PATERSON, N. J.

FROM RAW MATERIAL TO FINISHED PIPE

While to many users, the construction and manufacture of steel pipe is perhaps no secret, yet there are many novel processes involved in the manufacture of "LOCK-BAR" steel pipe which are of peculiar interest and are more or less unknown.

It is for this reason that a brief, non-technical description is given herewith.

Material Covered

1. This Specification covers three classes of material, namely: plates, lock-bars and rivet steel.

Process

2. The steel shall be made by the open-hearth process.

Discard

3. A sufficient discard shall be made from each ingot to insure sound material.

Chemical and Physical Properties

4. (a) The steel shall conform to the following requirements as to chemical and physical properties:

Properties Considered	*Plates*	*Lock-Bars*	*Rivet Steel*
Phosphorus	.04	.04	.04
Sulphur	.05	.05	.045
Yield Point, Min. lb. per sq. in.	0.5 T.S.	0.5 T.S.	0.5 T.S.
Tensile Strength, Min. lb. per sq. in.	55/65000	40/50000	46/56000
Elongation	$\frac{1{,}500{,}000}{\text{T.S.}}$	$\frac{1{,}500{,}000}{\text{T.S.}}$	$\frac{1{,}500{,}000}{\text{T.S.}}$

but need not exceed 30%

* See Section 7.

(b) The yield point shall be determined by the drop of the beam of the testing machine.

Ladle Analyses

5. An analysis of each melt of steel shall be made by the manufacturer to determine the percentages of carbon, manganese, phosphorus and sulphur. This analysis shall be made from a test ingot taken during the pouring of the melt. The chemical composition thus determined shall conform to the requirements specified in Section 4 (a) and shall be reported to the purchaser or his representative if requested.

Check Analyses

6. Analyses may be made by the purchaser from finished material representing each melt. The phosphorus and sulphur content thus determined shall not exceed that specified in Section 4 (a) by more than 25%.

Modifications in Elongation

7. (a) For plates over ¾" in thickness, a deduction of 1 from the percentage of elongation specified in Section 4 (a) shall be made for each increase of ⅛" in thickness above ¾".

(b) For plates under $\frac{5}{16}$" in thickness, a deduction of 2.5 from the percentage of elongation specified in Section 4 (a) shall be made for each decrease of $\frac{1}{16}$" in thickness below $\frac{5}{16}$".

Bend Tests

8. (a) The test specimen for plates shall be bent cold through 180° without cracking on the outside of the bent portion, as follows:

For material ¾" or under in thickness, flat on itself; for material over ¾" in thickness, around a pin the diameter of which is equal to the thickness of the specimen.

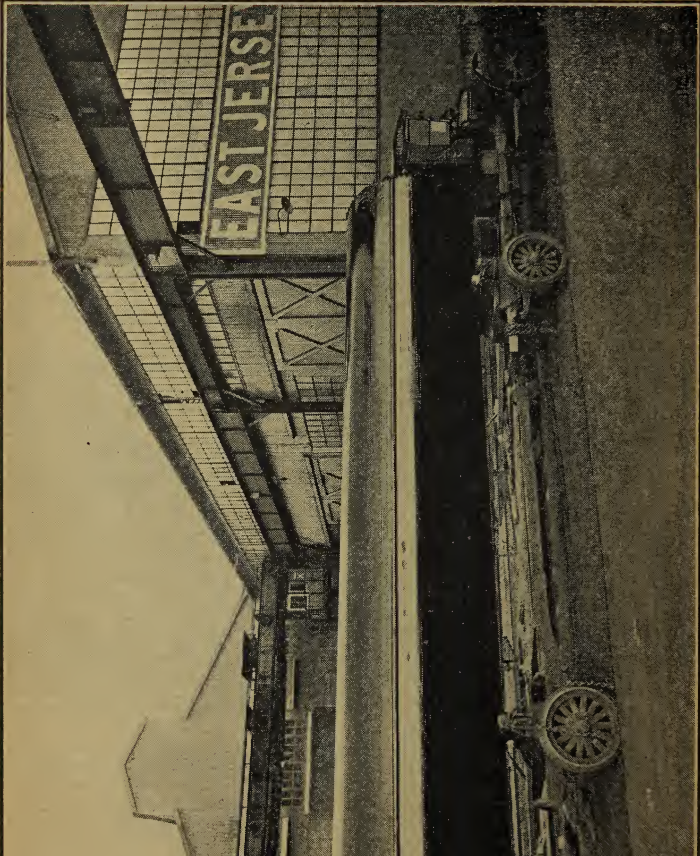


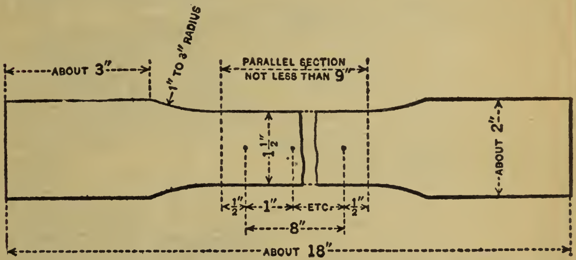
Fig. 2—TRANSPORTING "LOCK-BAR" PIPE BY MOTOR TRUCK

(b) The test specimen for Lock-Bar bars and rivet steel shall be bent cold through 180° flat on itself without cracking on the outside of the bent portion.

Test Specimens

9. (a) Tension and bend test specimens shall be taken from rolled steel in the condition in which it comes from the rolls and shall be of the full thickness or diameter of material as rolled except as specified in Paragraph (c).

(b) Tension and bend test specimens for plates may be machined to the form and dimensions shown herewith or with both edges parallel.



(c) Tension and bend test specimens for lock-bars may be machined to a rectangular section.

Number of Tests

10. (a) One tension and one bend test shall be made from each melt; except that if material from one melt differs ⅜" or more in thickness, one tension and one bend test shall be made from both the thickest and the thinnest material rolled.

(b) If any test specimen shows defective machining or develops flaws, it may be discarded and another specimen substituted.

(c) If the percentage of elongation of any tension test specimen is less than that specified in Section 4 (a) and any part of the fracture is outside the middle third of the gauge length, as indicated by scribe scratches marked on the specimen before testing, a retest shall be allowed.

Permissible Variations

11. The thickness of each plate shall not vary under the gauge specified more than 0.01". The over weight shall be within the limits adopted by The Association of American Steel Manufacturers for plates ordered to gauge.

Finish

12. The finished material shall be free from injurious defects and shall have a workmanlike finish.

Marking

13. The melt number shall be legibly stamped on all finished material, except that rivet steel and Lock-Bar bars may be shipped in securely fastened bundles with the melt number legibly stamped on attached metal tags. The melt number shall be legibly marked, by stamping if practicable, on each test specimen.

Inspection

14. The Inspector representing the purchaser shall have free entry at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works which concern the manufacture of the material ordered. The manufacturer shall afford the inspector, free of cost, all reasonable facilities to satisfy him that the material is being furnished in accordance with these specifications. All tests (except check analyses) and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

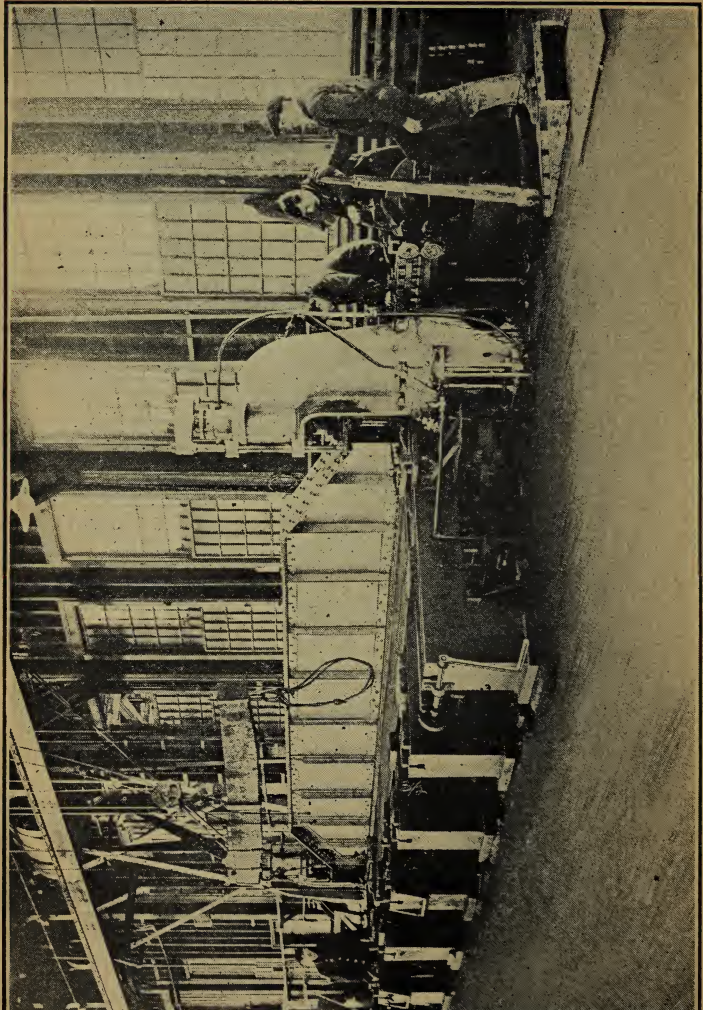


Fig. 3—THE PLANING MACHINE

SPECIFICATIONS FOR COATING

See page 21.

FABRICATING

The steel plates are delivered to the shop where they travel in progressive method of manufacture, from machine to machine, each designed to perform a particular part of the work, in a manner that insures within the machine itself, exact conformity to the specification requirements.

PLANING AND UP-SETTING

The design of "LOCK-BAR" pipe requires that the longitudinal edges of the plates shall be planed to the proper dimension and the edges up-set to a sufficient degree to form the necessary shoulder for engaging the lock-bar.

The steel plate 30 feet long, except where necessary to fit pipe to plan and profile of line, after passing inspection, is delivered to the planing and up-setting machine shown in Figure 3, and each longitudinal edge planed and up-set by a traveling carriage equipped with cutter and up-setting rolls, while being held fixedly in position by a hydraulic clamp running the full length of the machine. Figure 4 shows a close-up of the planing process and Figure 5 the up-setting.

When the plate leaves the planing and up-setting machine it is of taper section, to provide for taper joint laying.

Before proceeding further the edges are tested by gauging for up-set.

TRUING, PUNCHING AND BEVELING

The plate is then laid out for truing, punching and beveling on the ends, passing to the combination shearing and punching machine shown in Figure 6. It is trued and then punched by sharp, clean punches and dies, leaving clean holes without burrs.

From here it passes to the machine shown in Figure 7, where the ends are bevel-sheared for caulking purposes in laying, the bevel on each end being on opposite sides of the plate. Figure 8 shows a bevel-sheared end as it comes from the machine.

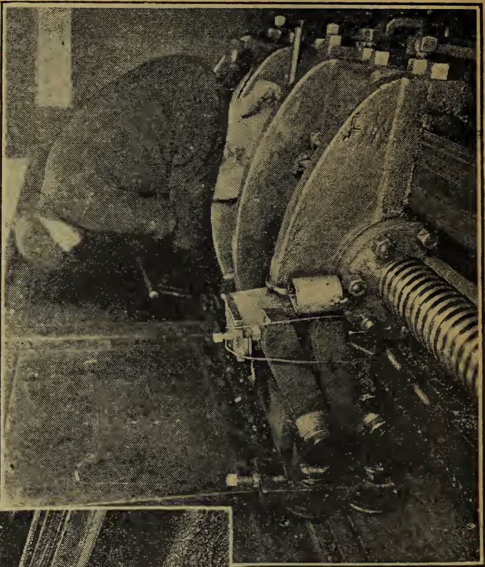


Fig. 5—UPSETTING THE EDGE OF PLATE

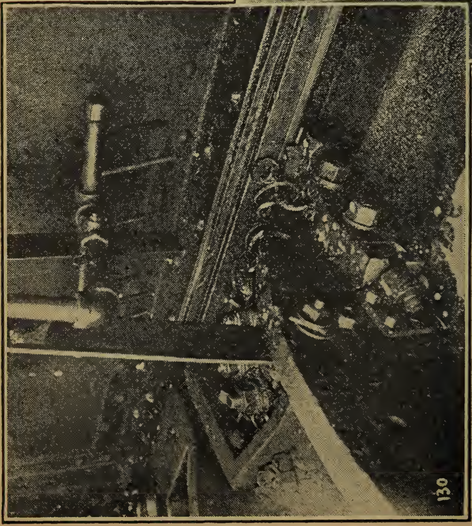


Fig. 4—PLANING THE STEEL PLATES

CRIMPING AND ROLLING

The plate passes to the crimping machine shown in Figure 9 where the longitudinal edges are crimped to the proper radius preparatory to rolling. The crimping is done so as to eliminate damage to the up-set edges in the rolls.

The plate is next cold rolled as shown in Figure 10, to the radius of the cylinder of the pipe.

ASSEMBLING

Assembling then begins, in pits arranged to accommodate them, passing through the several stages as follows: Figure 11, applying the lock-bars, previously scarf milled at opposite ends, see Figure 12. Figure 13, lowering mate-half into lock-bar. Figure 14, drawing up the several sections by means of heavy steel clamps.

The assembled pipe is now ready for the final fabricating process. It passes into the pressing machine shown in Figure 15,where both lock-bars are pressed down over the up-set edges of the plates by a hydraulic press, exerting a pressure of 350 tons per lineal foot of pipe.

TESTING

The pipe is now ready for testing. It is conveyed to the hydraulic testing machine, Figure 16, and subjected to a test 1-½ times the working pressure, undergoing a rigid inspection for leakage over the entire length of the lock-bar joints.

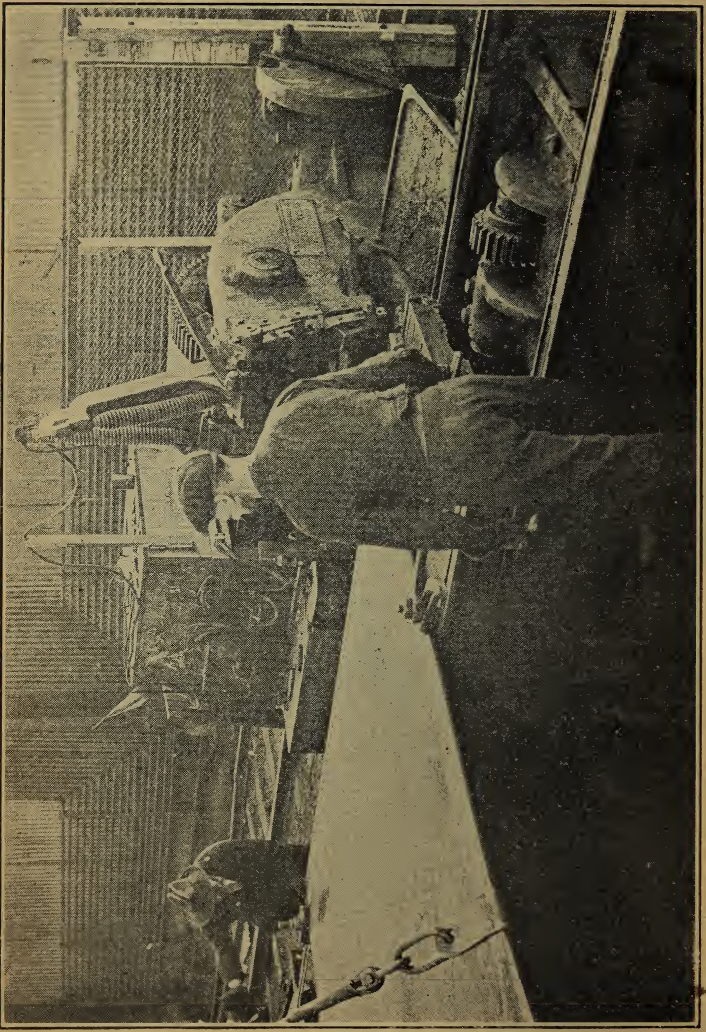


Fig. 6—SHEARING AND PUNCHING

COATING PIPE

Each length of pipe is thoroughly cleaned, all loose scale, rust, grease and dirt being removed. It then passes to the coating room where it is heated in the oven shown in Figure 17, to a temperature of from 350° F. to 400° F. Upon removal the pipe is then immersed in a vertical dipping tank, Figure 18, containing a bath of specially prepared coating which is also maintained at the correct temperature for dipping. This bath is deep enough to permit entire vertical submergence of the pipe. It receives a strongly adhering coating, $\frac{1}{32}$ inch or more in thickness, free from blisters and bubbles. This coating after setting will not become soft enough to flow at a temperature of 150° F. nor brittle enough to crack or scale off in freezing temperature.

After the pipe sections have been removed from the bath, they are set in vertical position, Figure 19, for cooling and when the coating has become hard are ready for loading.

Every engineer having to do with pipe lines knows that they should be protected against corrosion, inside and out.

Lock-Bar steel pipe is dipped vertically into a bath of specially prepared pipe-coating which embodies all the qualities that long experience in this field has shown to be essential.

This coating is proof against the corrosive action of ground water and of the acids and alkalis of the soil, and has the mechanical properties —toughness, tenacity and pliability—that are required to resist the abrasion and other abuse to which pipe is subject in handling and laying.

It is unaffected by the extremes of atmospheric temperature. It will neither crack and crocodile under the cold of winter, nor soften and run under the hottest summer sun. Throughout this entire range of temperature its consistency remains practically unchanged, and its sturdy toughness is as much in evidence at one extreme as at the other.

Such a coating makes for economy in two ways. Not only does it prolong the life of the pipe, but it also prevents the formation of tubercles and the resulting loss in carrying capacity. Taken together with the unobstructed cross-section and the smooth interior surface that are distinctive features of Lock-Bar pipe, this brings about a greater carrying capacity throughout the entire life of the pipe and insures the maximum of pipe-line efficiency.

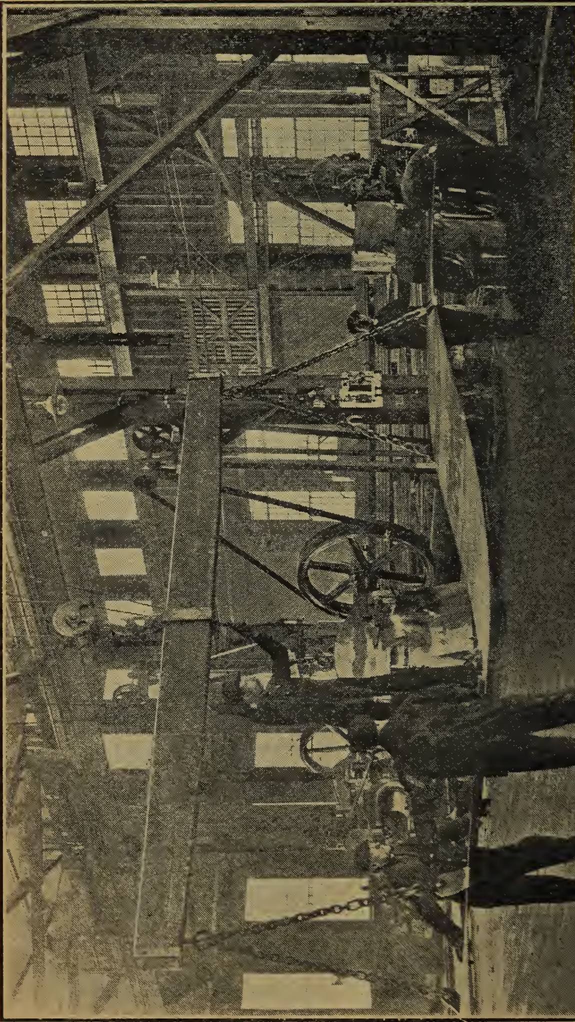


Fig. 7—BEVELING END OF PLATE

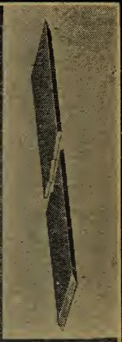


Fig. 8—PLATE BEVELED

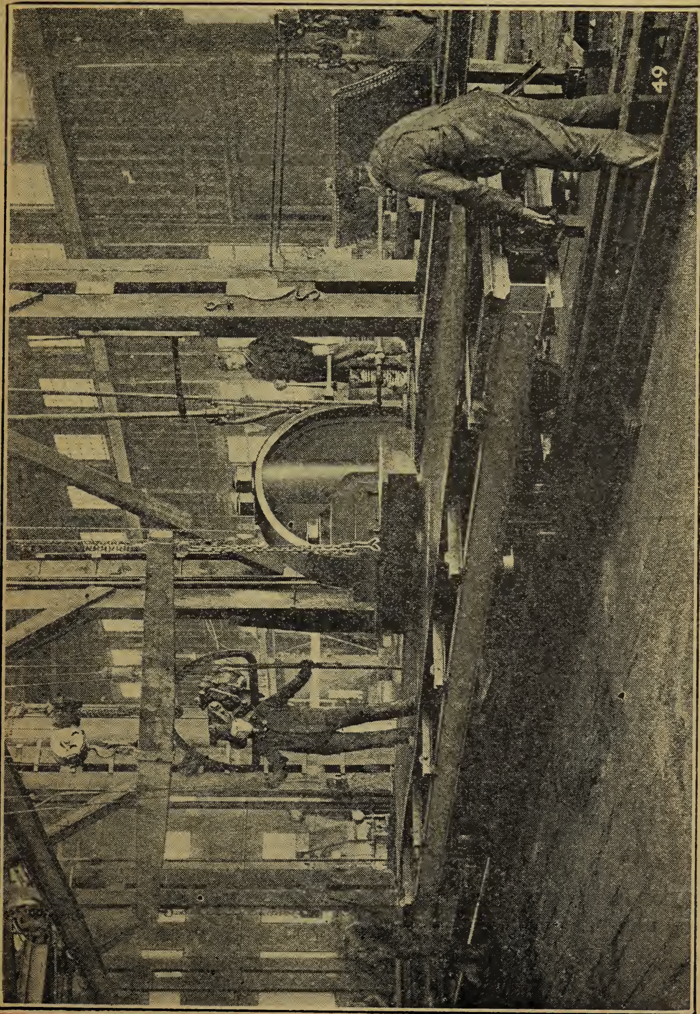


Fig. 9—CRIMPING EDGE PREPARATORY TO ROLLING

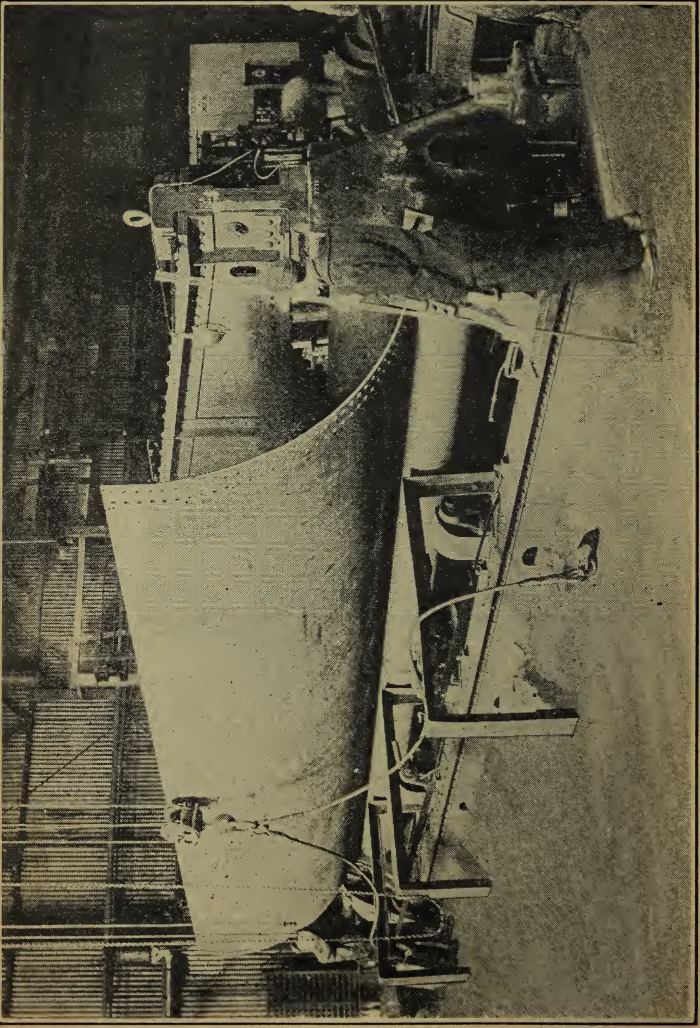


Fig. 10—ROLLING THE PLATE

GENERAL NOTES

1. All weights are figured on the basis of one cubic inch of steel weighing 0.2833 pounds.
2. All gross weights are figured on the basis of 30 foot lengths.
3. All weights given are limited to two decimal places.
4. All pipe diameter designations are inside dimensions.

MANUFACTURERS' STANDARD PRACTICE
PERMISSIBLE VARIATIONS IN GAUGE OF SHEARED PLATES
WHEN ORDERED TO THICKNESS

On **Carbon Steel Plates,** when ordered to thickness, the thickness of each plate shall not vary more than 0.01 inch under that ordered. The overweight of each lot in each shipment shall not exceed the amount given in the following table.

Ordered Gauge Inch	Permissible Excess in Average Weight per Square Foot of Plates for Width Given, Expressed in Percentage of Nominal Weight								
	Under 48 in.	48 in. incl. to 60 in. excl.	60 in. incl. to 72 in. excl.	72 in. incl. to 84 in. excl.	84 in. incl. to 96 in. excl.	96 in. incl. to 108 in excl.	108 in. incl. to 120 in. excl.	120 in. incl. to 132 in. excl.	132 in. and over
Under 1/8	9	10	12	14	..	..	..	..	..
1/8 incl. to 3/16 excl.	8	9	10	12	..	..	..	..	..
3/16 " " 1/4 "	7	8	9	10	12	..	..	..	..
1/4 " " 5/16 "	6	7	8	9	10	12	14	16	19
5/16 " " 3/8 "	5	6	7	8	9	10	12	14	17
3/8 " " 7/16 "	4.5	5	6	7	8	9	10	12	15
7/16 " " 1/2 "	4	4.5	5	6	7	8	9	10	13
1/2 " " 5/8 "	3.5	4	4.5	5	6	7	8	9	11
5/8 " " 3/4 "	3	3.5	4	4.5	5	6	7	8	9
3/4 " " 1 "	2.5	3	3.5	4	4.5	5	6	7	8
1 or over	2.5	2.5	3	3.5	4	4.5	5	6	7

The term "lot" applied to this table means all of the plates of each group width and group thickness.

MANUFACTURERS' STANDARD PRACTICE
PERMISSIBLE VARIATIONS IN WEIGHT OF SHEARED PLATES WHEN ORDERED TO WEIGHT

On **Carbon Steel Plates,** when ordered to weight per square foot the weight of each lot in each shipment shall not vary from the weight ordered, more than the amount given in the following table. The weight per square foot of individual plates shall not vary from the ordered weight by more than 1⅓ times the amount given.

Ordered Weight Pounds Per Square Foot	Permissible Variations in Average Weight per Square Foot of Plates for Width Given, Expressed in Percentage of Ordered Weight																	
	Under 48 in.		48 in. incl. to 60 in. excl.		60 in. incl. to 72 in. excl.		72 in. incl. to 84 in. excl.		84 in. incl. to 96 in. excl.		96 in. incl. to 108 in. excl.		108 in. incl. to 120 in. excl.		120 in. incl. to 132 in. excl.		132 in. and over	
	Over	Under	Over	Under	Over	Under	Over	Under	Over	Under	Over	Under	Over	Under	Over	Under	Over	Under
Under 5	5	3	5.5	3	6	3	7	3	...	...	...	...	...	...	...	...	...	...
5 incl. to 7.5 excl	4.5	3	5	3	5.5	3	6	3	...	...	...	...	...	...	...	...	...	...
7.5 " " 10 "	4	3	4.5	3	5	3	5.5	3	6	3	7	3	8	3	...	...	...	...
10 " " 12.5 "	3.5	2.5	4	3	4.5	3	5	3	5.5	3	6	3	7	3	8	3	9	3
12.5 " " 15 "	3	2.5	3.5	2.5	4	3	4.5	3	5	3	5.5	3	6	3	7	3	8	3
15 " " 17.5 "	2.5	2.5	3	2.5	3.5	2.5	4	3	4.5	3	5	3	5.5	3	6	3	7	3
17.5 " " 20 "	2.5	2	2.5	2.5	3	2.5	3.5	2.5	4	3	4.5	3	5	3	5.5	3	6	3
20 " " 25 "	2	2	2.5	2	2.5	2.5	3	2.5	3.5	2.5	4	3	4.5	3	5	3	5.5	3
25 " " 30 "	2	2	2	2	2.5	2	2.5	2.5	3	2.5	3.5	3	4	3	4.5	3	5	3
30 " " 40 "	2	2	2	2	2	2	2.5	2	2.5	2.5	3	2.5	3.5	3	4	3	4.5	3
40 or over	2	2	2	2	2	2	2	2	2.5	2	2.5	2.5	3	2.5	3.5	3	4	3

The term "lot" applied to this table means all of the plates of each group width and group weight.

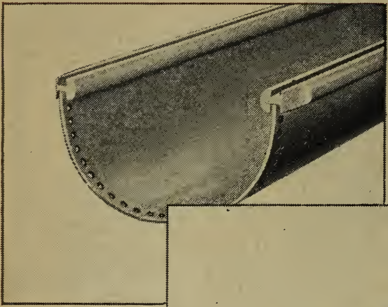


Fig. 11
Applying
The "Lock-Bars"

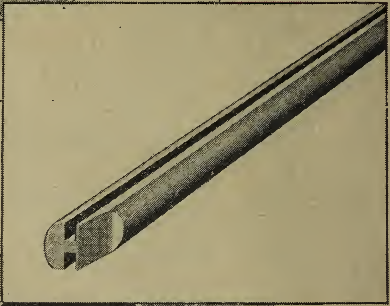


Fig. 12
Scarfed
"Lock-Bar"

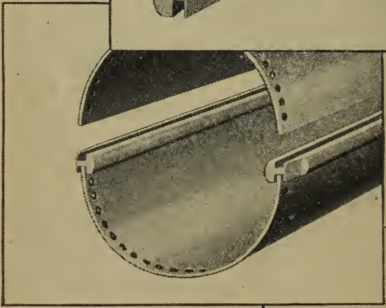


Fig. 13
Assembling
Halves

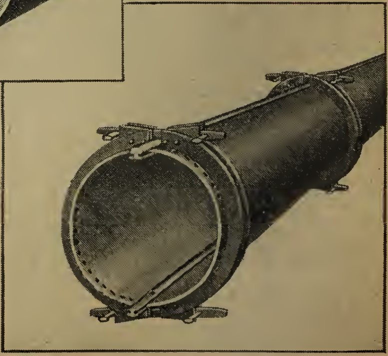


Fig. 14
Drawing up
Before
Pressing

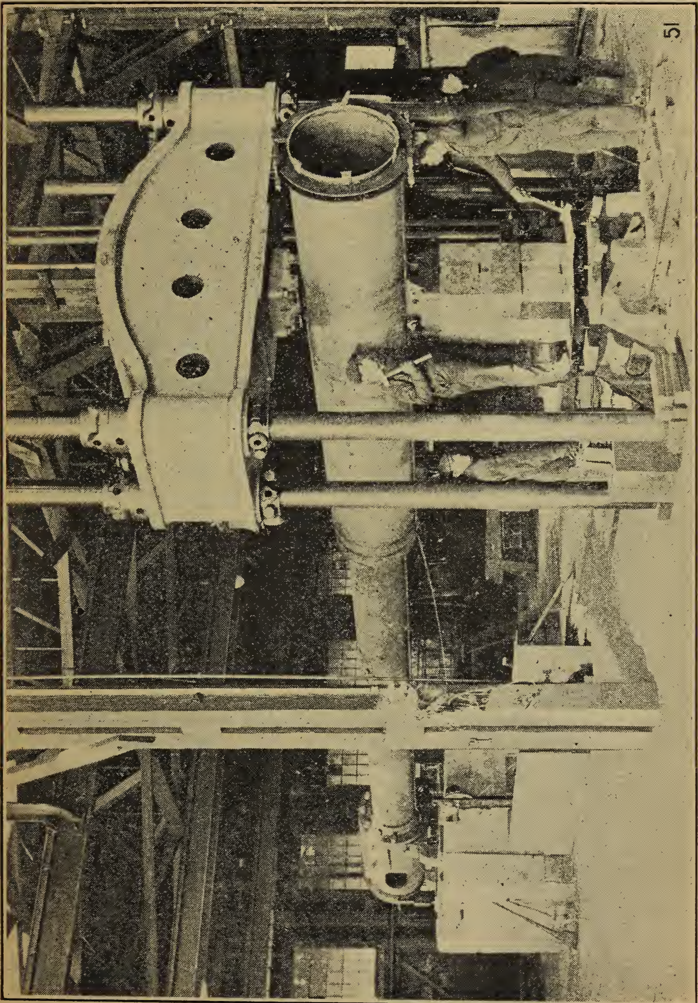


Fig. 15—PRESSING THE LONGITUDINAL LOCK-BAR JOINT

APPROXIMATE FINISHED WEIGHTS PER FOOT OF DOUBLE LOCK-BAR PIPE

Including Plate, Lock-bars, Rivets and Coating

Dia.	$\frac{3}{16}''$	$\frac{1}{4}''$	$\frac{5}{16}''$	$\frac{3}{8}''$	$\frac{7}{16}''$	$\frac{1}{2}''$
	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.
20″	57.03	74.00	91.30	113.50	137.30	150.80
22″	61.74	79.62	98.10	122.06	146.70	162.50
24″	66.46	85.24	104.85	130.60	156.00	174.40
26″	71.18	91.32	112.47	138.90	165.60	185.37
28″	75.90	97.23	119.85	147.52	175.20	196.34
30″	80.64	102.95	126.96	156.47	184.81	207.31
32″	85.11	108.87	134.38	165.11	195.22	219.27
34″	89.58	114.98	141.95	173.43	205.88	231.23
36″	94.06	121.25	149.60	181.40	216.72	243.20
38″	98.43	127.83	157.82	191.72	226.32	255.87
40″	102.80	134.19	165.45	200.67	236.94	268.54
42″	107.18	140.30	172.49	208.29	248.47	281.22
44″	112.67	147.33	181.57	218.59	259.18	291.69
46″	118.16	154.36	190.65	228.89	269.89	302.16
48″	123.67	161.40	199.72	239.20	280.60	312.60
50″	......	168.01	206.53	248.13	290.94	324.61
52″	......	174.62	213.34	257.06	301.28	336.62
54″	......	181.25	220.15	266.00	311.62	348.65
56″	......	187.52	228.78	274.97	323.24	361.93
58″	......	193.79	237.41	283.94	334.86	375.21
60″	......	200.05	246.05	292.90	346.50	388.50
62″	......	208.00	254.34	307.28	357.84	401.50
64″	......	215.95	262.63	317.60	369.18	414.50
66″	......	223.91	270.94	323.86	380.52	427.52
68″	......	231.19	280.23	333.83	391.68	439.52
70″	......	238.47	289.52	343.80	402.84	451.52
72″	......	245.76	298.81	353.76	414.00	463.53

APPROXIMATE FINISHED WEIGHTS PER FOOT OF DOUBLE RIVETED STEEL PIPE

Including Plate, Rivets and Coating

Dia.	$\frac{3}{16}$"	¼"	$\frac{5}{16}$"	⅜"	$\frac{7}{16}$"	½"
	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.
20″	52.50	70.20	89.20	108.10	125.98	145.10
22″	57.22	76.45	96.55	117.25	136.89	157.70
24″	61.95	82.70	103.90	126.40	147.80	170.30
26″	66.61	88.98	111.15	134.81	158.71	181.61
28″	71.27	95.26	118.40	143.22	169.62	192.92
30″	76.00	101.55	125.65	151.65	180.55	204.25
32″	80.90	107.73	133.23	160.66	191.53	216.00
34″	85.80	113.91	140.81	169.67	202.51	227.75
36″	90.70	120.10	148.40	178.70	213.50	239.50
38″	95.88	126.61	155.81	188.50	224.62	252.08
40″	101.06	133.12	163.22	198.30	235.71	264.66
42″	106.25	139.65	170.65	208.05	246.85	277.25
44″	111.03	145.76	179.63	217.50	256.90	289.83
46″	115.81	151.87	188.61	226.45	266.95	302.41
48″	120.60	158.00	197.60	236.40	277.00	315.00
50″	124.99	164.15	205.31	246.08	288.61	326.85
52″	129.38	170.30	213.02	255.76	300.22	338.70
54″	133.75	176.45	220.75	265.45	311.85	350.55
56″	138.46	182.86	228.13	274.56	322.63	363.76
58″	143.17	189.27	235.51	283.67	333.41	374.97
60″	147.90	195.70	242.90	292.80	344.20	387.20
62″	153.70	202.30	251.65	302.28	355.08	399.25
64″	159.50	208.90	260.40	311.76	365.96	411.30
66″	165.25	215.50	269.15	321.25	376.85	423.35
68″	171.10	222.17	277.20	330.70	387.43	435.70
70″	176.90	228.84	285.25	340.15	398.01	448.05
72″	182.70	235.50	293.30	349.60	408.60	460.40

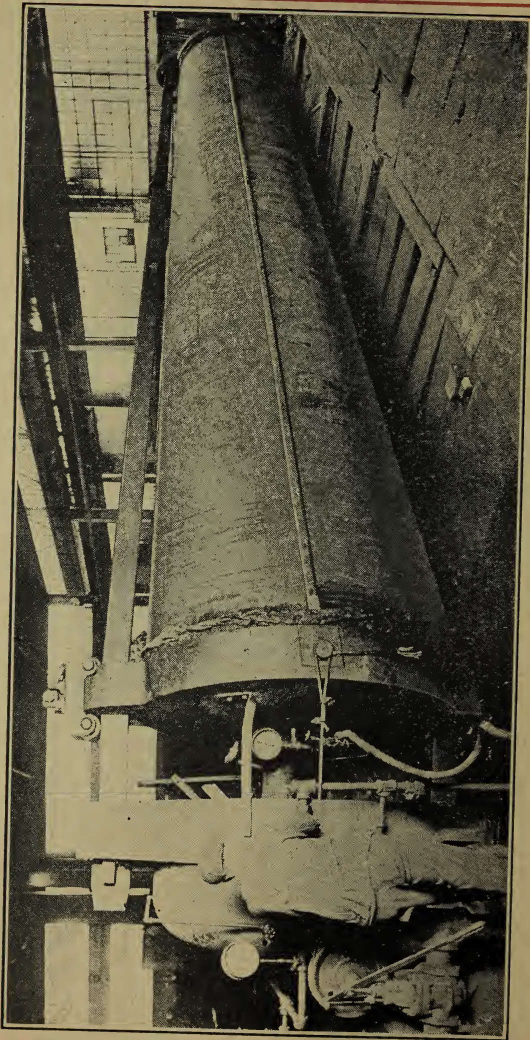


Fig. 16—TESTING "LOCK-BAR" PIPE

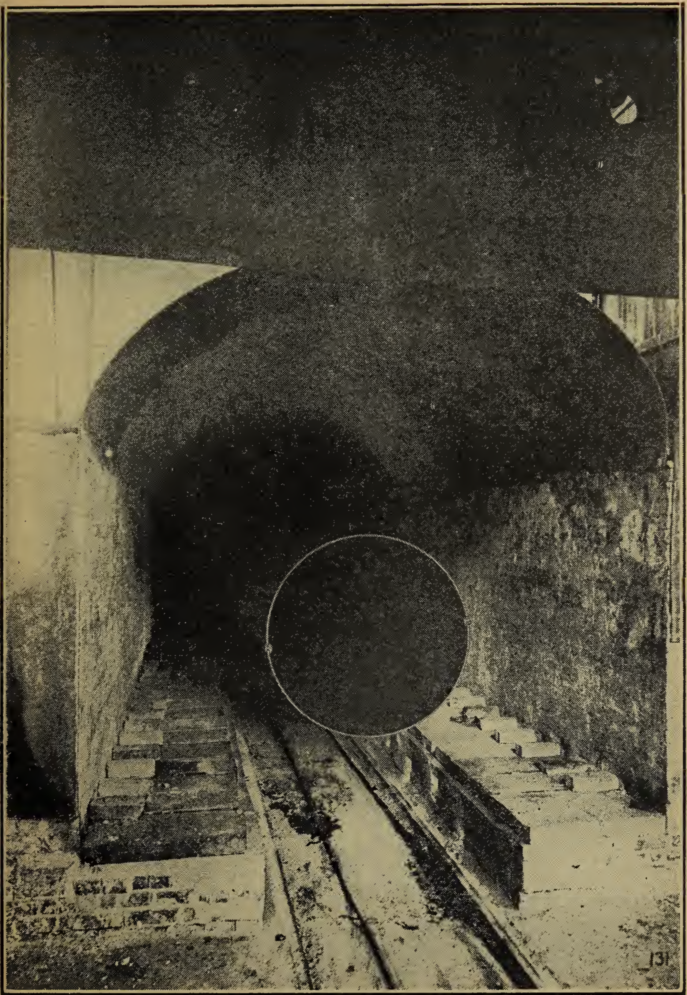


Fig. 17—Oven where Lock-Bar is heated before Dipping in Coating

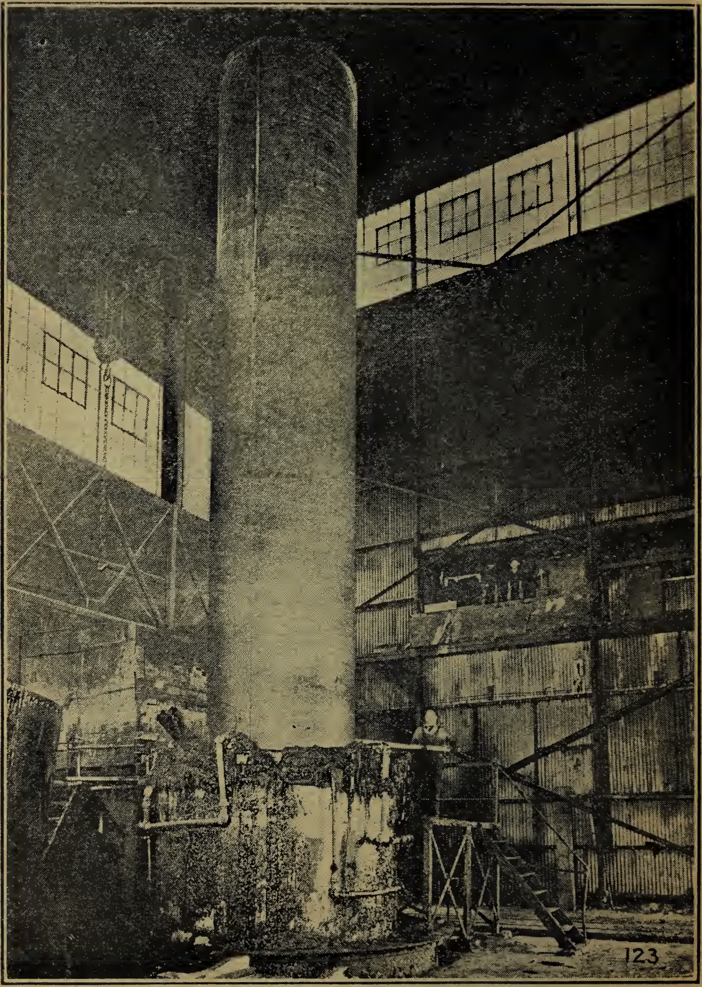


Fig. 18—VERTICALLY DIPPING "LOCK-BAR" PIPE

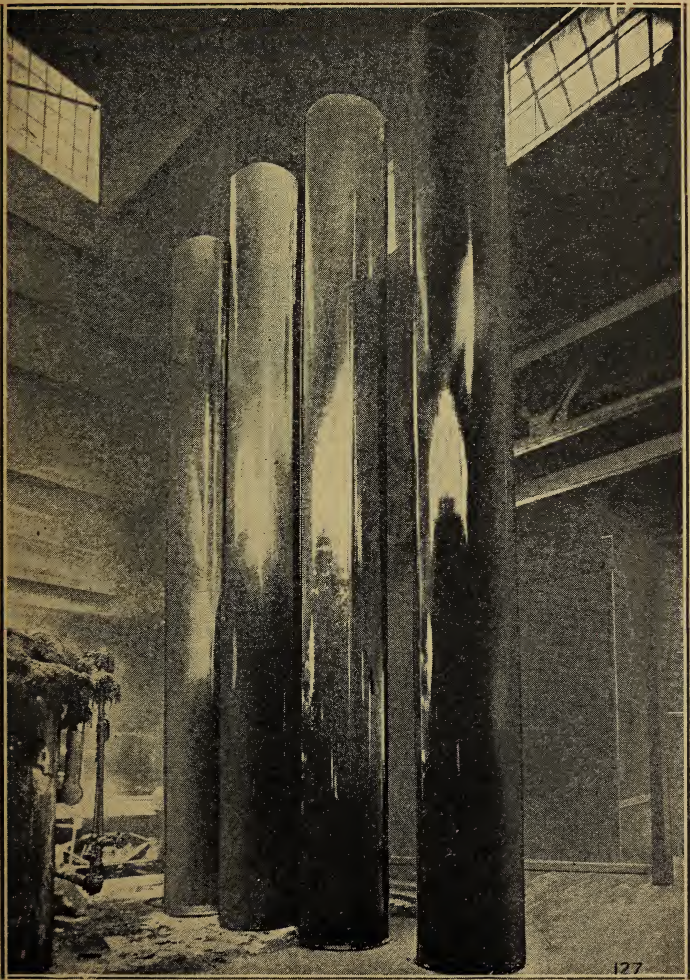


Fig. 19—"LOCK-BAR" PIPE COOLING AFTER DIPPING

Fig. 20

RIVETED TAPER JOINT

The most successful type of field seam for ordinary installations where the pipe diameter is sufficiently large for riveting and caulking on the inside. The larger end of the pipe fits over the smaller or taper end of the contiguous pipe. After riveting, the joint is caulked both inside and out. All interior seams point in the direction of the line of flow.

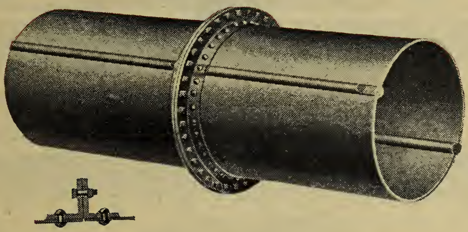


Fig. 21

FLANGE JOINT

Flanges are cast steel. These joints are suitable for both high and low pressure service. They are furnished riveted onto pipe ends, ready for connecting.

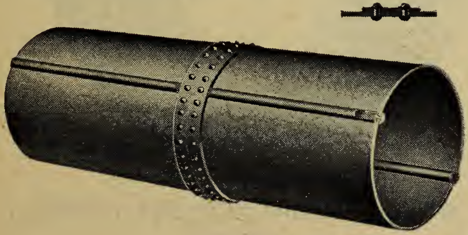
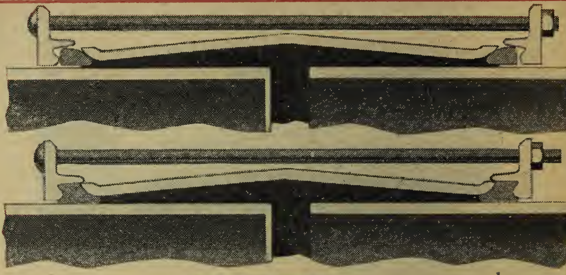


Fig. 22

BUTT STRAP JOINT

Butt Strap Joints are sometimes furnished to meet peculiar conditions of installation.



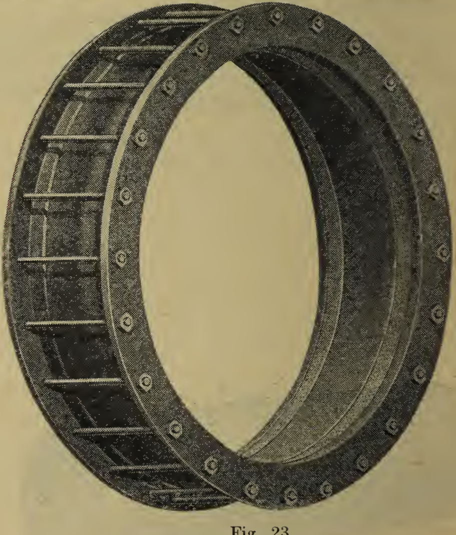


Fig. 23

HIGH PRESSURE FLEXIBLE COUPLING

(Patented)

This joint is suitable for all high pressure work and forms a perfect expansion joint and flexible coupling, permitting deflection of the line at each joint. It consists of rolled steel follower rings, through-bolted, and seated on rubber gaskets against a steel center ring. It has given eminently satisfactory service wherever used. Especially adapted for gas lines. Advantageously used for diameters too small for riveted taper joint.

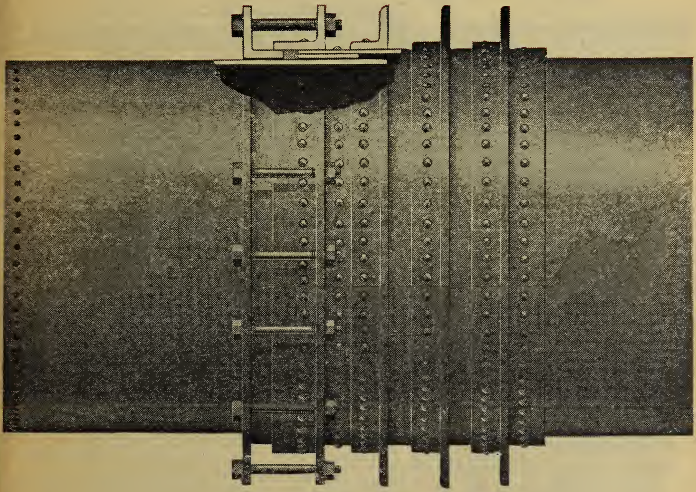


Fig. 24

EAST JERSEY EXPANSION JOINT

(Patented)

An expansion joint that functions perfectly under all conditions of service. It stays tight and puts the minimum strain on the line. Two anchorage angles are shown in the above cut at the right of joint.

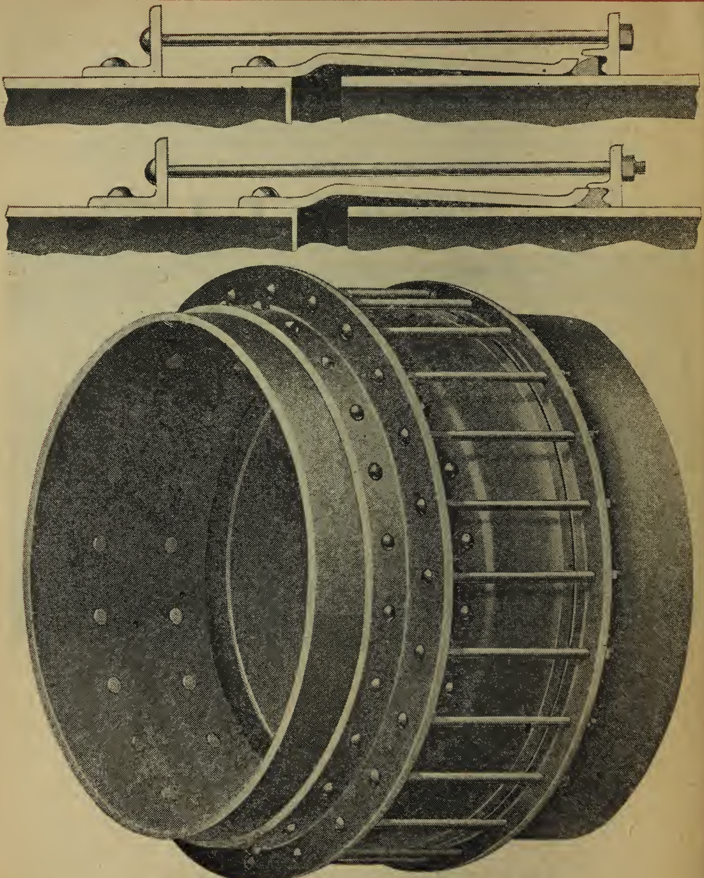


Fig. 25

SUBMARINE JOINT

(Patented)

A desirable joint for submerged lines because of the ease with which the joint is assembled and made tight under working conditions. A follower ring seating on a rubber gasket and drawn to closed position by large bolts, seals the joint. This design also constitutes an expansion joint and will permit considerable deflection.

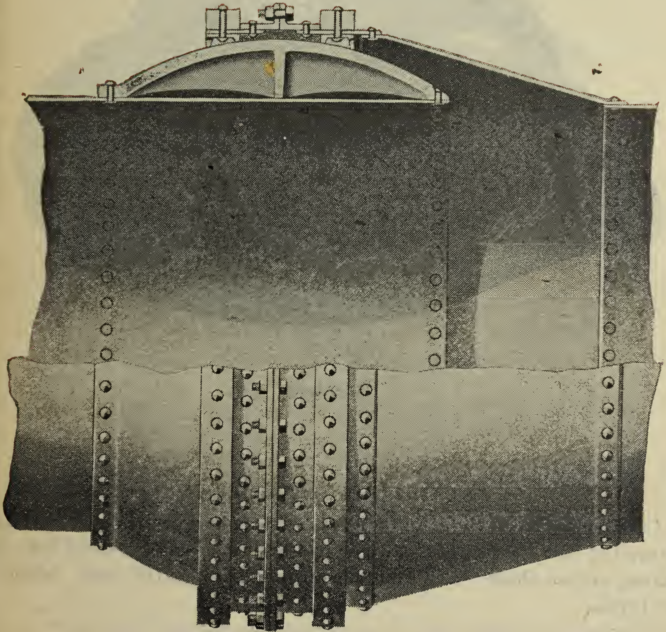


Fig. 26

FLEXIBLE SUBMARINE JOINT

Occasionally used on submarine lines requiring exceptional deflection.

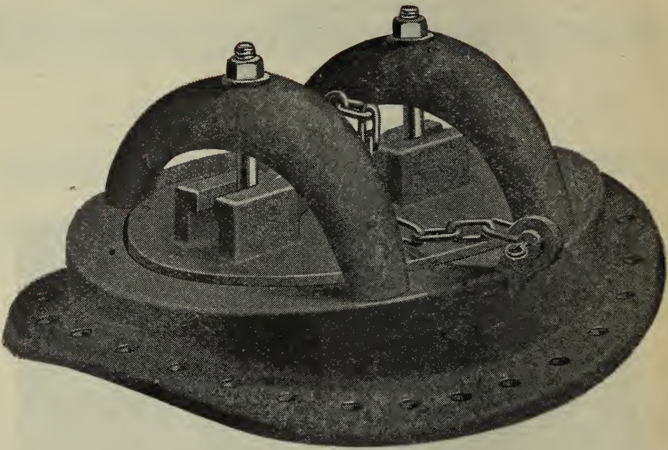


Fig. 27

Patented

STANDARD MANHOLES

Conforming to all the requirements of safety and convenience. Manufactured of cast steel with cast iron cover and arches. It is provided with a strong anchor chain. The Manhole opening is 14″ x 16″ oval. Made in four types.

Type	Description	Number of holes	Diameter of holes	Weight
A	For $\frac{3}{16}$″ Plate.	36	$\frac{11}{16}$″	215 lbs.
B	For ¼″ and $\frac{5}{16}$″ Plate. . . .	32	$\frac{13}{16}$″	215 lbs.
C	For ⅜″ and $\frac{7}{16}$″ Plate. . . .	24	$\frac{15}{16}$″	215 lbs.
D	For ½″ Plate.	24	$1\frac{1}{16}$″	215 lbs.

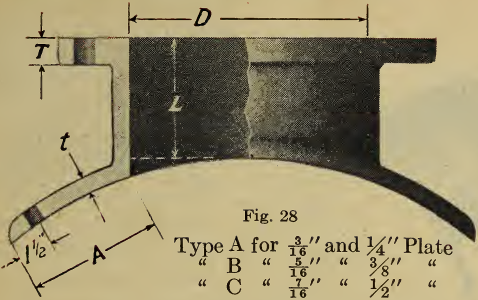


Fig. 28

Type A for 3/16" and ¼" Plate
" B " 5/16" " ⅜" "
" C " 7/16" " ½" "

STRAIGHT SADDLES—125 lbs. pressure

Manufactured of cast steel and amply heavy to stand up under duty without fear of breakage. Provided with flange end and made in the several sizes listed.

Diam. D	Length L	Thickness t	Thickness T	A	Saddle Flange			Straight Flange			
					Type	No. of Holes	Dia. of Holes	O. D.	B. C.	No. of Holes	Size of Holes
4	4	⅝	⅞	5	A B C	20 16 12	11/16 13/16 1 1/16	9	7½	8	¾
6	4⅝	⅝	1	5½	A B C	24 20 16	11/16 13/16 1 1/16	11	9½	8	⅞
8	4¾	¾	1	5¾	A B C	28 24 16	11/16 13/16 1 1/16	13½	11¾	8	⅞
10	4¾	¾	1	6	A B C	28 24 16	11/16 13/16 1 1/16	16	14¼	12	1
12	5¾	¾	1⅛	6½	A B C	32 28 20	11/16 13/16 1 1/16	19	17	12	1
16	5⅞	⅞	1⅛	6¾	A B C	36 32 24	11/16 13/16 1 1/16	23½	21¼	16	1⅛
20	6⅞	⅞	1⅛	6¾	A B C	48 44 36	11/16 13/16 1 1/16	27½	25	20	1¼
24	6⅞	⅞	1¼	6¾	A B C	48 44 36	11/16 13/16 1 1/16	32	29½	20	1⅜
30	8	1	1¼	7	A B C	56 32 44	11/16 13/16 1 1/16	38¾	36	28	1½
36	10	1⅛	1½	7¼	A B C	64 60 52	11/16 13/16 1 1/16	46	42¾	32	1⅝
48	10	1⅛	1½	7¾	A B C	76 72 64	11/16 13/16 1 1/16	59½	56	44	1¾

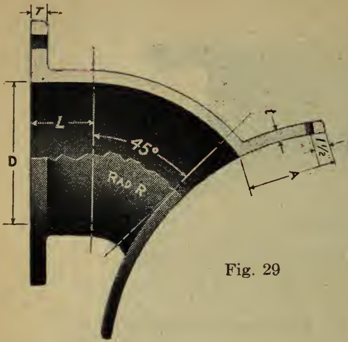


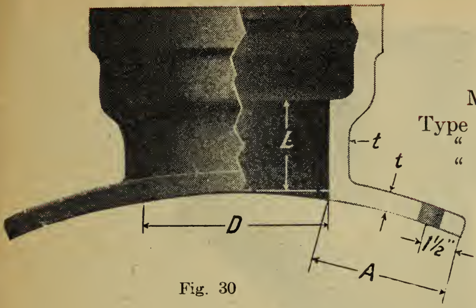
Fig. 29

Type A for $\frac{3}{16}$ and ¼ Plate
" B " $\frac{5}{16}$ " ⅜ "
" C " $\frac{7}{16}$ " ½ "

STANDARD BLOW OFF CONNECTIONS

Manufactured of cast steel, with ample metal at all points. Flange joint connection. Built in the several sizes listed.

Diam-D	Length L	Thickness t	Thickness T	A	Radius R	Saddle Flange			Straight Flange			
						Type	No. of Holes	Dia. of Holes	O. D.	B. C.	No. of Holes	Size of Holes
4″	3″	⅝″	⅞″	5″	6″	A B C	20 16 12	$\frac{11}{16}$″ $\frac{13}{16}$″ 1 $\frac{1}{16}$″	9″	7½″	8	¾″
6″	4″	⅝″	1″	5½″	7″	A B C	24 20 16	$\frac{11}{16}$″ $\frac{13}{16}$″ 1 $\frac{1}{16}$″	11″	9½″	8	⅞″
8″	4″	¾″	1″	5¾″	8½″	A B C	28 24 16	$\frac{11}{16}$″ $\frac{13}{16}$″ 1 $\frac{1}{16}$″	13½″	11¾″	8	⅞″
10″	4″	¾″	1″	6″	8 $\frac{11}{16}$″	A B C	28 24 16	$\frac{11}{16}$″ $\frac{13}{16}$″ 1 $\frac{1}{16}$″	16″	14¼″	12	1″
12″	5″	¾″	1⅛″	6½″	9¼″	A B C	32 28 20	$\frac{11}{16}$″ $\frac{13}{16}$″ 1 $\frac{1}{16}$″	19″	17″	12	1″
16″	5″	⅞″	1⅛″	6¾″	11″	A B C	36 32 24	$\frac{11}{16}$″ $\frac{13}{16}$″ 1 $\frac{1}{16}$″	23½″	21¼″	16	1⅛″
20″	5″	⅞″	1⅛″	6¾″	13½″	A B C	48 44 36	$\frac{11}{16}$″ $\frac{13}{16}$″ 1 $\frac{1}{16}$″	27½″	25″	20	1¼″
24″	5″	⅞″	1¼″	6¾″	16″	A B C	48 44 36	$\frac{11}{16}$″ $\frac{13}{16}$″ 1 $\frac{1}{16}$″	32″	29½″	20	1⅜″
30″	5″	1″	1¼″	7″	19″	A B C	56 32 44	$\frac{11}{16}$″ $\frac{13}{16}$″ 1 $\frac{1}{16}$″	38¾″	36″	28	1½″
36″	6″	1⅛″	1½″	7¼″	22″	A B C	64 60 52	$\frac{11}{16}$″ $\frac{13}{16}$″ 1 $\frac{1}{16}$″	46″	42¾″	32	1⅝″
48″	7″	1⅛″	1½″	7¾″	28″	A B C	76 72 64	$\frac{11}{16}$″ $\frac{13}{16}$″ 1 $\frac{1}{16}$″	59½″	56″	44	1¾″



Made in three Types
Type A for $\frac{3}{16}''$ and $\frac{1}{4}''$ Plate
" B " $\frac{5}{16}''$ " $\frac{3}{8}''$ "
" C " $\frac{7}{16}''$ " $\frac{1}{2}''$ "

Fig. 30

STANDARD SOCKET SADDLES
New England Water Works Association Standard.

Dia. D	Length L	Thickness t	A	Saddle Flange Type	No. of Holes	Dia of Holes
6″	4⅝″	⅝″	5½″	A	24	$\frac{11}{16}''$
				B	20	$\frac{13}{16}''$
				C	16	$1\frac{1}{16}''$
8″	4¾″	¾″	5¾″	A	28	$\frac{11}{16}''$
				B	24	$\frac{13}{16}''$
				C	16	$1\frac{1}{16}''$
10″	4¾″	¾″	6″	A	28	$\frac{11}{16}''$
				B	24	$\frac{13}{16}''$
				C	16	$1\frac{1}{16}''$
12″	5¾″	¾″	6½″	A	32	$\frac{11}{16}''$
				B	28	$\frac{13}{16}''$
				C	20	$1\frac{1}{16}''$
16″	5⅞″	⅞″	6¾″	A	36	$\frac{11}{16}''$
				B	32	$\frac{13}{16}''$
				C	24	$1\frac{1}{16}''$
20″	6⅞″	⅞″	6¾″	A	48	$\frac{11}{16}''$
				B	44	$\frac{13}{16}''$
				C	36	$1\frac{1}{16}''$
24″	6⅞″	⅞″	6¾″	A	48	$\frac{11}{16}''$
				B	44	$\frac{13}{16}''$
				C	36	$1\frac{1}{16}''$
30″	8″	1″	7″	A	36	$\frac{11}{16}''$
				B	52	$\frac{13}{16}''$
				C	44	$1\frac{1}{16}''$
36″	10″	1⅛″	7¼″	A	64	$\frac{11}{16}''$
				B	60	$\frac{13}{16}''$
				C	52	$1\frac{1}{16}''$
48″	10″	1⅛″	7¾″	A	76	$\frac{11}{16}''$
				B	72	$\frac{13}{16}''$
				C	64	$1\frac{1}{16}''$
4″	6¼″	⅝″	4″	A	16	$\frac{11}{16}''$
				B	12	$\frac{13}{16}''$
				C	8	$1\frac{1}{16}''$

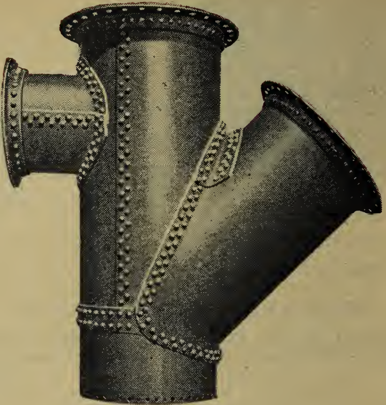


Fig. 31

Y's AND TEES

Specials are manufactured to meet all conditions. They are fabricated of steel plate and furnished with either riveted or flanged connections.

Fig. 32

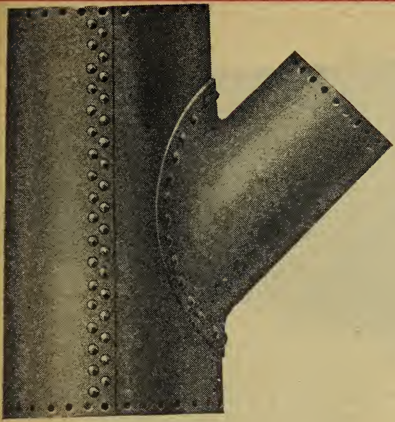


Fig. 33

Fig. 34

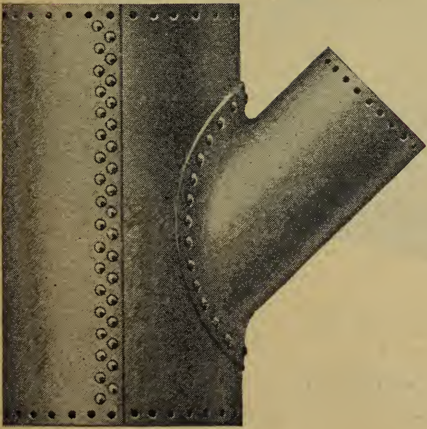


Fig. 35

TYPES OF RIVETED
SPECIALS

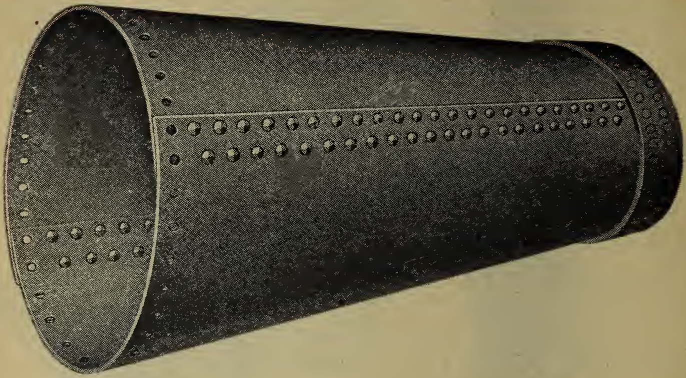


Fig. 36

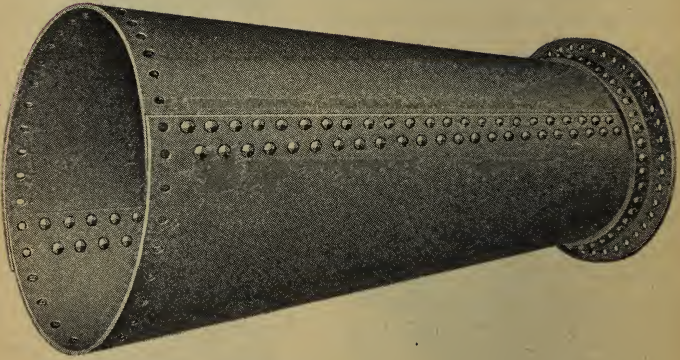


Fig. 37

REDUCERS

Riveted Steel Plate Reducers are made up to meet all conditions.

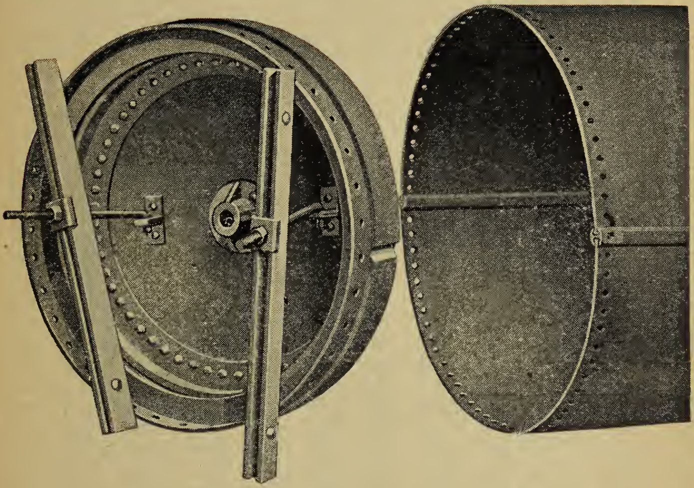


Fig. 38

FIELD TEST HEAD
(Patented)

The Company is prepared to rent field test apparatus to be used by the field contractor for testing the tightness of pipe joints after riveting in the field.

This apparatus comprises a steel plate dished head riveted to a cast iron ring and provided with a rubber gasket.

In using this device an angle ring which is provided is bolted inside the pipe end after placing the head and rubber gasket inside the pipe.

Two hook bolts and cross members are used to draw the head forward against the rubber gasket forcing it against the angle ring.

This test apparatus has been widely used and has given entire satisfaction. It is built with a wide factor of safety.

SAFE WORKING PRESSURE FOR LOCK-BAR PIPE

Dia.	3/16″ Lb.	1/4″ Lb.	5/16″ Lb.	3/8″ Lb.	7/16″ Lb.	Dia.	3/16″ Lb.	1/4″ Lb.	5/16″ Lb.	3/8″ Lb.	7/16″ Lb.
20″	258	344	430	515	601	47″	110	146	183	219	256
21″	246	328	410	490	573	48″	107	143	179	214	250
22″	234	312	391	469	545	49″	105	140	176	210	245
23″	224	298	374	447	522	50″	103	137	172	206	240
24″	215	286	358	430	501	51″	101	135	169	202	236
25″	206	274	344	412	480	52″	99	132	165	198	231
26″	198	264	331	396	462	53″	97	130	162	194	227
27″	191	254	318	382	445	54″	96	127	159	191	223
28″	184	244	308	368	428	55″	94	125	156	188	218
29″	178	236	297	356	414	56″	92	122	153	184	214
30″	172	229	287	344	400	57″	90	120	151	180	211
31″	166	222	278	332	388	58″	89	118	148	178	207
32″	161	214	269	322	375	59″	87	116	146	175	204
33″	156	208	260	312	364	60″	86	114	143	172	200
34″	152	202	253	304	354	61″	84	112	141	169	197
35″	147	196	246	294	343	62″	83	111	139	166	194
36″	143	191	239	286	334	63″	82	109	136	164	190
37″	139	185	232	278	324	64″	80	107	134	161	188
38″	136	181	226	271	317	65″	79	106	132	158	185
39″	132	176	220	264	308	66″	78	104	130	156	182
40″	129	172	215	258	300	67″	77	102	128	153	179
41″	126	167	210	252	393	68″	76	101	126	151	177
42″	123	163	205	246	286	69″	75	100	125	149	175
43″	120	159	200	240	280	70″	73	98	123	147	171
44″	117	156	195	234	274	71″	72	97	121	145	170
45″	115	152	191	229	268	72″	72	95	119	143	167
46″	112	149	187	224	262						

T.S. = 55,000 lbs.
f = 4 factor of safety
r = Radius
e = 100% eff. of joint
P = Safe working pressure
t = Thickness of plate

$$t = \frac{P \times r \times f}{T.S.}$$

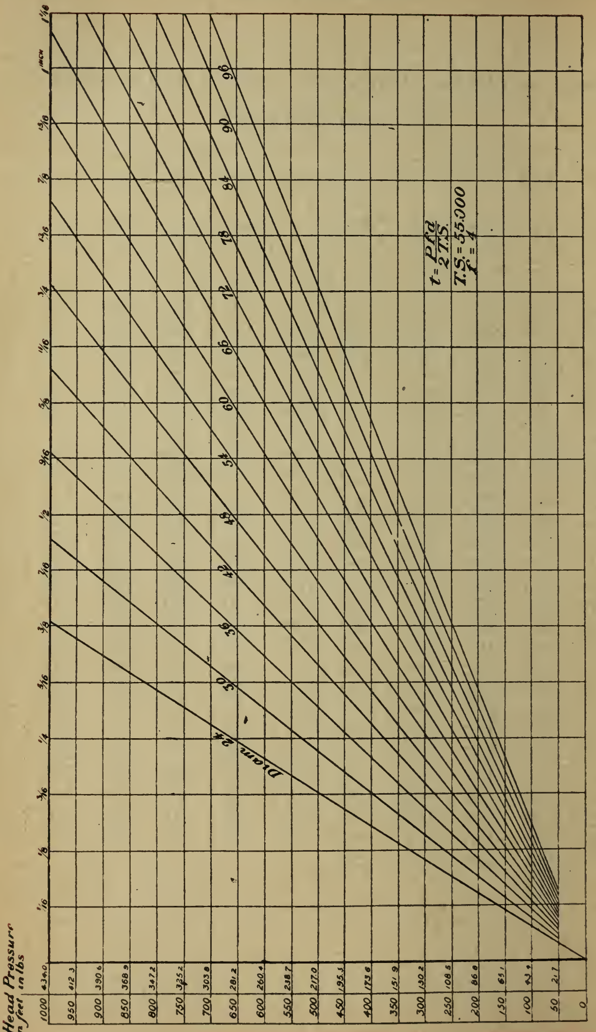
$$P = \frac{t \times T.S.}{r \times f}$$

Safe working pressure for double riveted pipe 70% of pressure given in table.

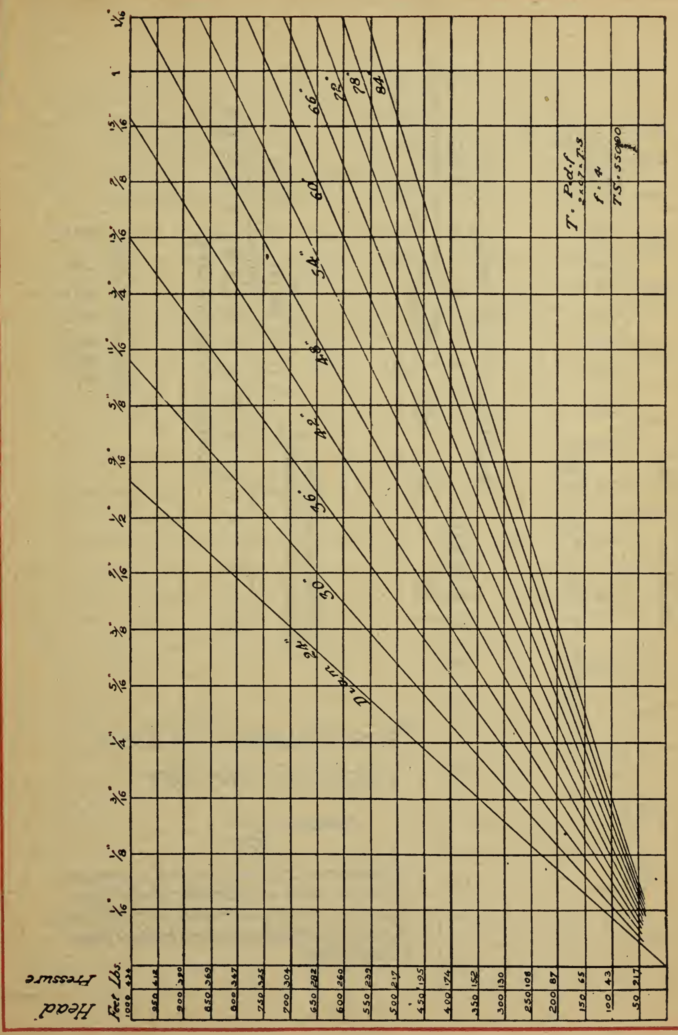
SAFE WORKING PRESSURE FOR RIVETED PIPE

70% Joint Efficiency

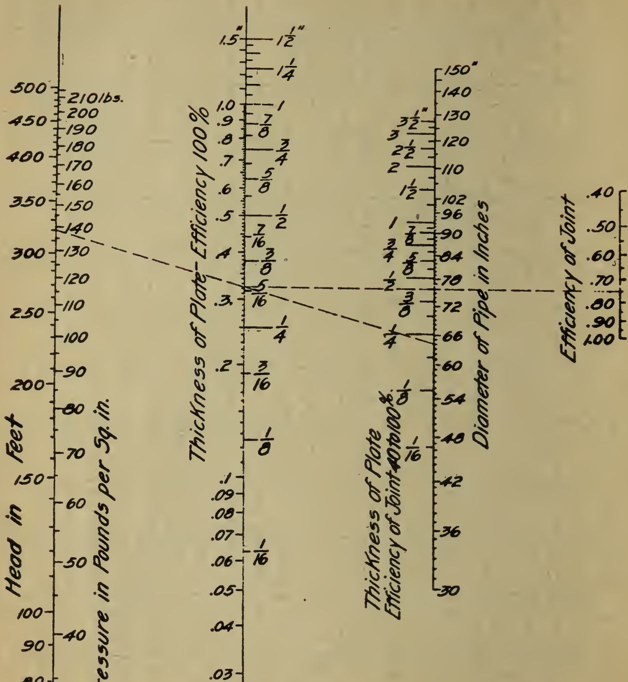
Dia.	3/16″ Lb.	1/4″ Lb.	5/16″ Lb.	3/8″ Lb.	7/16″ Lb.	Dia.	3/16″ Lb.	1/4″ Lb.	5/16″ Lb.	3/8″ Lb.	7/16″ Lb.
20″	180	240	300	360	420	47″	77	103	128	154	180
21″	172	230	287	343	400	48″	75	100	125	150	175
22″	163	218	271	326	380	49″	73	98	122	146	170
23″	156	208	260	312	364	50″	72	96	120	144	168
24″	150	200	250	300	350	51″	71	95	118	142	165
25″	144	192	240	288	336	52″	69	92	115	138	160
26″	139	185	232	278	324	53″	68	91	113	136	158
27″	134	178	223	268	312	54″	67	89	112	134	156
28″	129	171	215	258	300	55″	66	88	110	132	154
29″	125	167	208	250	292	56″	64	85	107	128	149
30″	120	160	200	240	280	57″	63	84	105	126	147
31″	116	155	193	232	270	58″	62	83	103	124	145
32″	113	150	188	226	264	59″	61	81	102	122	142
33″	109	145	182	218	254	60″	60	80	100	120	140
34″	106	141	176	212	247	61″	59	79	98	118	137
35″	103	137	171	206	240	62″	58	77	97	116	135
36″	100	133	167	200	234	63″	57	76	95	114	133
37″	98	130	163	196	228	64″	56	75	93	112	130
38″	95	127	158	190	222	65″	55	73	92	110	128
39″	92	123	153	184	214	66″	54	72	90	108	126
40″	90	120	150	180	210	67″	54	72	90	108	126
41″	88	117	147	176	205	68″	53	71	88	106	123
42″	86	115	143	172	200	69″	52	69	87	104	121
43″	84	112	140	168	196	70″	51	68	85	102	119
44″	82	109	136	164	191	71″	50	67	83	100	117
45″	81	108	135	162	189	72″	50	67	83	100	117
46″	78	104	130	156	182						



Safe Working Pressure.
LOCK-BAR PIPE



Safe Working Pressure.
DOUBLE RIVETED PIPE



Pressure-Diameter-Thickness Diagram for Steel Pipe

Formula – $t = \frac{pdf}{2et_s}$

t = thickness of plate in inches, p = pressure in lbs per sq. in., d = diameter of steel pipe, in inches, f = factor of safety = 4, e = efficiency of joint, t_s = ultimate strength of steel plate = 55000 lbs.

Steel Pipe, either Riveted or Lock-Bar, within ordinary limits can be made of any required diameter. In this respect it differs from cast iron pipe, which is commonly made only of the sizes for which the foundries have molds. The diameter should always be specified as the smallest diameter of the smallest ring, where the rings are not all of the same size.

Weight of Steel Pipe. The finished weight of steel pipe per lineal foot, either Riveted or Lock-Bar, including the excess weight of plates rolled so that the thinnest points in the plate will be approximately of the nominal thickness, and including the laps, rivets and lock bars, material in the joints and coating, may be found approximately by the formula:

Weight in lbs. per foot = (12.5 x diameter x thickness) + 10 lbs. in which diameter and thickness are to be taken in inches. The weight of commonly used sizes are given in the tables on pages 30 and 31.

Thickness of Steel Pipe. (See formula on charts, pages 50 and 54.)

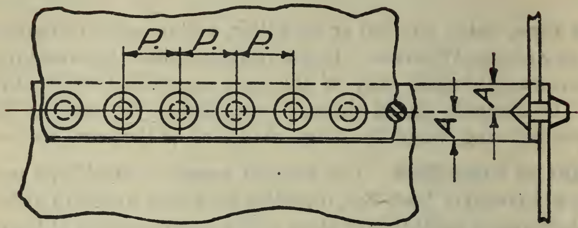
Riveted Pipe. The older lines of steel pipe prior to the introduction of Lock-Bar and Welded, were all riveted. Generally riveted pipe is made up of steel plates seven or eight feet wide, which are bent so that one sheet goes entirely around, forming one section of pipe. Four of these sheets are riveted together in the shop, making a length of pipe 28 to 30 feet long. This is tested for tightness and dipped in protective coating, and then shipped to the place where it is to be used.

The circular seams may be single riveted. The longitudinal seams which alone are required to carry the stress due to the pressure of the water are at least double riveted, except where the pressure is very low.

IN-AND-OUT courses are used, alternate rings being larger and smaller. TAPER LENGTHS are also used in which one end of each pipe is smaller than the other end and will slip into the large end of the next length. Pipes have also been made with all the lengths the same size fastened together with butt straps on the outside, but as this is a more expensive method it has not been often used.

Continuous Riveting has been used in nearly all American steel pipe lines; that is, each length of pipe in the field has been tightly riveted to its neighbors. Practical experience with this system of construction has been satisfactory.

SINGLE RIVETED LAP JOINTS



T.S.—55,000 pounds. S.S.—42,000 pounds

Thickness of Plate Inches	Diameter of Cold Rivet Inches	Maximum Diameter of Rivet Hole Inches	Efficiency in Per Cent	Pitch of Rivets "P" Inches	Gauge "A" Inches
3/16	1/2	9/16	60.8	1 7/16	27/32
7/32	1/2	9/16	60.8	1 7/16	27/32
*1/4	9/16	5/8	58.3	1 1/2	15/16
1/4	5/8	11/16	59.2	1 11/16	1 1/32
*9/32	5/8	11/16	59.2	1 11/16	1 1/32
*5/16	11/16	3/4	58.6	1 13/16	1 1/8
11/32	11/16	3/4	58.6	1 13/16	1 1/8
*11/32	13/16	7/8	58.8	2 1/8	1 5/16
*3/8	13/16	7/8	57.6	2 1/8	1 5/16
3/8	7/8	15/16	58.3	2 1/4	1 13/32
*13/32	7/8	15/16	57.6	2 1/4	1 13/32
*7/16	15/16	1	57.7	2 3/8	1 1/2
7/16	1	1 1/16	56.4	2 7/16	1 19/32
*15/32	1	1 1/16	56.4	2 7/16	1 19/32
*1/2	1	1 1/16	54.8	2 15/32	1 19/32
17/32	1	1 1/16	51.7	2 15/32	1 19/32
9/16	1	1 1/16	48.7	2 15/32	1 19/32
19/32	1	1 1/16	46.1	2 15/32	1 19/32
5/8	1 1/8	1 3/16	48.6	2 25/32	1 25/32
21/32	1 1/8	1 3/16	46.3	2 25/32	1 25/32
11/16	1 1/8	1 3/16	44.2	2 25/32	1 25/32
23/32	1 1/8	1 3/16	42.3	2 25/32	1 25/32
3/4	1 1/8	1 3/16	40.5	2 25/32	1 25/32

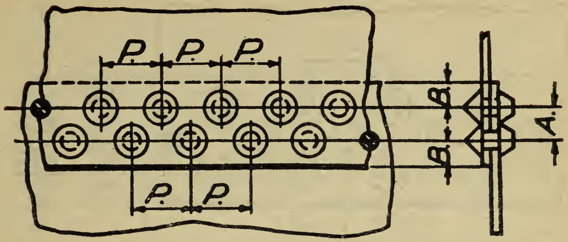
*Designed and Recommended by Hartford Stm. Blr. Insp. and Ins. Co.

SINGLE RIVETED LAP GIRTH JOINTS

Designed and Recommended by Hartford Stm. Blr. Insp. and Ins. Co.
For use when Rivets of same diameter are used in Girth and Longitudinal Joints.

Diameter of Cold Rivet, Inches	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/16	1 1/8	1 3/16	1 1/4
Maximum Diameter of Rivet Hole, Inches	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/16	1 1/8	1 3/16	1 1/4	1 5/16
Pitch of Rivets "P," Inches	1 5/8	1 3/4	1 7/8	2	2 1/8	2 1/4	2 3/8	2 7/16	2 1/2	2 3/4	2 7/8	3 1/16	3 1/4
Gauge "A," Inches	7/8	15/16	1 1/16	1 1/8	1 1/4	1 5/16	1 7/16	1 1/2	1 5/8	1 11/16	1 13/16	1 7/8	2

DOUBLE RIVETED LAP JOINTS

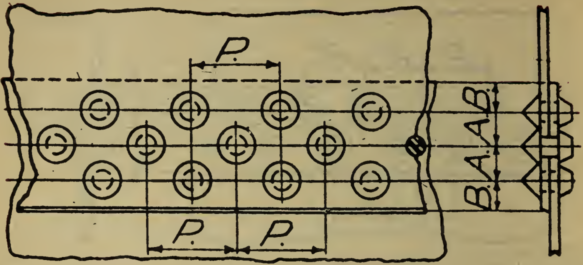


T.S.—55,000 pounds. S.S.—42,000 pounds.

Thickness of Plate Inches	Diameter of Cold Rivet Inches	Maximum Diameter of Rivet Hole Inches	Efficiency in Per Cent	Pitch of Rivets "P" Inches	Space "A" Inches	Gauge "B" Inches
3/16	1/2	9/16	75.0	2 1/4	1 5/16	27/32
7/32	1/2	9/16	75.0	2 1/4	1 5/16	27/32
*1/4	9/16	5/8	73.6	2 3/8	1 7/16	15/16
1/4	5/8	11/16	71.8	2 7/16	1 15/32	1 1/32
*9/32	9/16	5/8	72.0	2 5/16	1 13/32	15/16
9/32	5/8	11/16	71.8	2 7/16	1 15/32	1 1/32
*5/16	5/8	11/16	71.8	2 7/16	1 15/32	1 1/32
*11/32	11/16	3/4	72.0	2 11/16	1 5/8	1 1/8
*3/8	3/4	13/16	71.7	2 7/8	1 5/8	1 7/32
*13/32	3/4	13/16	70.0	2 25/32	1 21/32	1 7/32
*7/16	7/8	15/16	70.0	3 1/8	1 7/8	1 13/32
*15/32	7/8	15/16	70.0	3 1/8	1 7/8	1 13/32
*1/2	15/16	1	70.3	3 3/8	2	1 1/2
1/2	1	1 1/16	70.4	3 19/32	2 1/8	1 19/32
17/32	1	1 1/16	70.4	3 19/32	2 1/8	1 19/32
9/16	1	1 1/16	66.9	3 19/32	2 1/8	1 19/32
19/32	1	1 1/16	63.4	3 19/32	2 1/8	1 19/32
5/8	1	1 1/16	60.2	3 19/32	2 1/8	1 19/32
21/32	1 1/8	1 3/16	65.9	3 29/32	2 11/32	1 25/32
11/16	1 1/8	1 3/16	62.9	3 29/32	2 11/32	1 25/32
23/32	1 1/8	1 3/16	60.2	3 29/32	2 11/32	1 25/32
3/4	1 1/8	1 3/16	57.7	3 29/32	2 11/32	1 25/32
25/32	1 1/4	1 5/16	60.8	4 11/32	2 1/2	1 31/32
13/16	1 1/4	1 5/16	58.5	4 11/32	2 1/2	1 31/32
27/32	1 1/4	1 5/16	56.3	4 11/32	2 1/2	1 31/32
7/8	1 1/4	1 5/16	54.3	4 11/32	2 1/2	1 31/32

*Designed and Recommended by Hartford Stm. Blr. Insp. and Ins. Co.

TRIPLE RIVETED LAP JOINTS

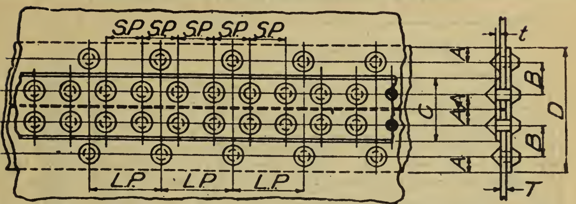


T.S.—55,000 pounds. S.S.—42,000 pounds

Thickness of Plate Inches	Diameter of Cold Rivet Inches	Maximum Diameter of Rivet Hole Inches	Efficiency in Per Cent	Pitch of Rivets "P" Inches	Space "A" Inches	Gauge "B" Inches
3/16	1/2	9/16	78.5	2 5/8	1 5/8	7/8
7/32	1/2	9/16	78.5	2 5/8	1 5/8	7/8
1/4	1/2	9/16	78.5	2 5/8	1 5/8	7/8
*1/4	9/16	5/8	78.2	2 7/8	1 3/4	15/16
*9/32	9/16	5/8	78.2	2 7/8	1 3/4	15/16
9/32	5/8	11/16	77.0	3	1 7/8	1 1/16
*5/16	5/8	11/16	77.0	3	1 7/8	1 1/16
*11/32	5/8	11/16	77.0	3	1 7/8	1 1/16
*3/8	3/4	13/16	75.0	3 1/4	2 1/8	1 7/32
*13/32	3/4	13/16	75.0	3 1/4	2 1/8	1 7/32
*7/16	13/16	7/8	75.0	3 1/2	2 1/4	1 5/16
7/16	7/8	15/16	75.0	3 3/4	2 3/8	1 13/32
*15/32	7/8	15/16	75.0	3 3/4	2 3/8	1 13/32
*1/2	7/8	15/16	75.0	3 3/4	2 3/8	1 13/32
17/32	7/8	15/16	75.0	3 3/4	2 3/8	1 13/32
9/16	7/8	15/16	74.9	3 3/4	2 3/8	1 13/32
19/32	1	1 1/16	75.0	4 1/4	2 11/16	1 19/32
5/8	1	1 1/16	75.0	4 1/4	2 11/16	1 19/32
21/32	1	1 1/16	72.8	4 1/4	2 11/16	1 19/32
11/16	1	1 1/16	69.5	4 1/4	2 11/16	1 19/32
23/32	1	1 1/16	66.4	4 1/4	2 11/16	1 19/32
3/4	1 1/8	1 3/16	71.2	4 3/4	2 13/16	1 25/32
25/32	1 1/8	1 3/16	68.3	4 3/4	2 13/16	1 25/32
13/16	1 1/8	1 3/16	65.7	4 3/4	2 13/16	1 25/32
27/32	1 1/8	1 3/16	63.3	4 3/4	2 13/16	1 25/32
7/8	1 1/4	1 5/16	70.8	5	2 7/8	1 31/32
29/32	1 1/4	1 5/16	68.4	5	2 7/8	1 31/32
15/16	1 1/4	1 5/16	66.1	5	2 7/8	1 31/32
31/32	1 1/4	1 5/16	63.9	5	2 7/8	1 31/32
.	1 1/4	1 5/16	62.0	5	2 7/8	1 31/32

*Designed and Recommended by Hartford Stm. Blr. Insp. and Ins. Co.

DOUBLE RIVETED BUTT JOINTS



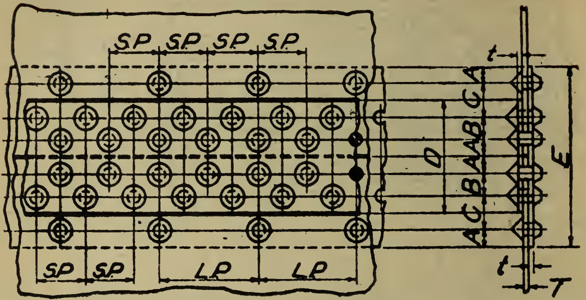
T.S. 55,000 pounds.
C.S. 95,000 pounds.

Single S.S.—42,000 pounds.
Double S.S—78,000 pounds.

Thickness of Plate "T" Inches	Diameter of Cold Rivet Inches	Maximum Diameter of Rivet Hole Inches	Efficiency in Per Cent	Long Pitch of Rivets "L. P." Inches	Short Pitch of Rivets "S. P." Inches	Gauge "A" Inches	Space "B" Inches	Width of Outside Strap "C" Inches	Width of Inside Strap "D" Inches	Thickness of Straps "t" Inches
*1/4	5/8	11/16	80.7	3 9/16	1 25/32	1 1/32	2 1/16	4 1/8	8 1/4	1/4
*9/32	5/8	11/16	80.7	3 9/16	1 25/32	1 1/32	2 1/16	4 1/8	8 1/4	1/4
*5/16	11/16	3/4	80.6	3 7/8	1 15/16	1 1/8	2 1/4	4 1/2	9	9/32
*11/32	11/16	3/4	80.6	3 7/8	1 15/16	1 1/8	2 1/4	4 1/2	9	9/32
*3/8	3/4	13/16	80.8	4 1/4	2 1/8	1 7/32	2 7/16	4 7/8	9 3/4	5/16
*13/32	3/4	13/16	80.8	4 1/4	2 1/8	1 7/32	2 7/16	4 7/8	9 3/4	11/32
7/16	3/4	13/16	80.8	4 1/4	2 1/8	1 7/32	2 7/16	4 7/8	9 3/4	3/8
*7/16	13/16	7/8	80.5	4 1/2	2 1/4	1 5/16	2 5/8	5 1/4	10 1/2	3/8
*15/32	13/16	7/8	81.0	4 5/8	2 5/16	1 5/16	2 5/8	5 1/4	10 1/2	13/32
15/32	7/8	15/16	80.2	4 3/4	2 3/8	1 13/32	2 13/16	5 5/8	11 1/4	13/32
*1/2	7/8	15/16	80.2	4 3/4	2 3/8	1 13/32	2 13/16	5 5/8	11 1/4	7/16
17/32	7/8	15/16	80.7	4 7/8	2 7/16	1 13/32	2 13/16	5 5/8	11 1/4	15/32
9/16	7/8	15/16	80.7	4 7/8	2 7/16	1 13/32	2 13/16	5 5/8	11 1/4	1/2
19/32	1	1 1/16	80.7	5 1/2	2 3/4	1 19/32	3 3/16	6 3/8	12 3/4	17/32
5/8	1	1 1/16	80.6	5 1/2	2 3/4	1 19/32	3 3/16	6 3/8	12 3/4	9/16
21/32	1	1 1/16	80.1	5 1/2	2 3/4	1 19/32	3 3/16	6 3/8	12 3/4	19/32
11/16	1	1 1/16	79.2	5 1/2	2 3/4	1 19/32	3 3/16	6 3/8	12 3/4	5/8
23/32	1	1 1/16	78.4	5 1/2	2 3/4	1 19/32	3 3/16	6 3/8	12 3/4	5/8
3/4	1 1/8	1 3/16	79.8	6 3/16	3 3/32	1 25/32	3 9/16	7 1/8	14 1/4	5/8
25/32	1 1/8	1 3/16	79.1	6 3/16	3 3/32	1 25/32	3 9/16	7 1/8	14 1/4	21/32
13/16	1 1/8	1 3/16	78.5	6 1/4	3 1/8	1 25/32	3 9/16	7 1/8	14 1/4	11/16
27/32	1 1/4	1 5/16	79.4	6 13/16	3 13/32	1 31/32	3 15/16	7 7/8	15 3/4	23/32
7/8	1 1/4	1 5/16	78.8	6 13/16	3 13/32	1 31/32	3 15/16	7 7/8	15 3/4	3/4
29/32	1 1/4	1 5/16	78.2	6 13/16	3 13/32	1 31/32	3 15/16	7 7/8	15 3/4	25/32
15/16	1 1/4	1 5/16	76.2	6 13/16	3 13/32	1 31/32	3 15/16	7 7/8	15 3/4	13/16
31/32	1 1/4	1 5/16	73.8	6 13/16	3 13/32	1 31/32	3 15/16	7 7/8	15 3/4	13/16
1	1 1/4	1 5/16	71.4	6 13/16	3 13/32	1 31/32	3 15/16	7 7/8	15 3/4	27/32

*Designed and Recommended by Hartford Stm. Blr. Insp. and Ins. Co.

TRIPLE RIVETED BUTT JOINTS

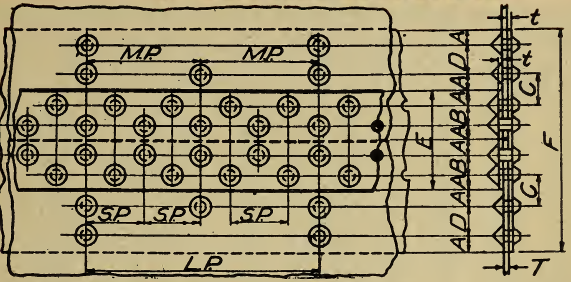


T. S.—55,000 lbs. Single S. S.—42,000 lbs. C. S.—95,000 lbs. Double S. S.—78,000 lbs.

Thickness of Plate "T" Inches	Diameter of Cold Rivet Inches	Maximum Diameter of Rivet Hole Inches	Efficiency in Per Cent	Long Pitch "L. P." Inches	Short Pitch "S. P." Inches	Gauge "A" Inches	Space "B" Inches	Space "C" Inches	Width of outside Strap "D" Inches	Width of Inside Strap "E" Inches	Thickness of Straps "t" Inches
1/4	1/2	9/16	87.5	4 1/2	2 1/4	27/32	1 3/8	1 11/16	6 1/8	9 1/2	3/16
*9/32	1/2	9/16	87.5	4 1/2	2 1/4	27/32	1 3/8	1 11/16	6 1/8	9 1/2	3/16
9/32	9/16	5/8	86.3	4 9/16	2 9/32	15/16	1 3/8	1 7/8	6 1/2	10 1/4	3/16
5/16	11/16	3/4	88.0	6 1/4	3 1/8	1 1/8	1 7/8	2 1/4	8 1/4	12 3/4	1/4
11/32	11/16	3/4	88.0	6 1/4	3 1/8	1 1/8	1 7/8	2 1/4	8 1/4	12 3/4	1/4
3/8	3/4	13/16	87.5	6 1/2	3 1/4	1 7/32	2	2 7/16	8 7/8	13 3/4	5/16
13/32	3/4	13/16	87.7	6 5/8	3 5/16	1 7/32	2	2 7/16	8 7/8	13 3/4	5/16
7/16	7/8	15/16	86.1	6 3/4	3 3/8	1 13/32	2 1/32	2 13/16	9 11/16	15 5/16	3/8
15/32	7/8	15/16	86.6	7	3 1/2	1 13/32	2 1/8	2 13/16	9 7/8	15 1/2	3/8
1/2	1	1 1/16	85.8	7 1/2	3 3/4	1 19/32	2 1/4	3 3/16	10 7/8	17 1/4	3/8
17/32	1	1 1/16	85.8	7 1/2	3 3/4	1 19/32	2 1/4	3 3/16	10 7/8	17 1/4	13/32
9/16	1	1 1/16	85.9	7 9/16	3 25/32	1 19/32	2 9/32	3 3/16	10 15/16	17 5/16	7/16
19/32	1	1 1/16	86.0	7 5/8	3 13/16	1 19/32	2 9/32	3 3/16	10 15/16	17 5/16	7/16
5/8	1	1 1/16	86.3	7 3/4	3 7/8	1 19/32	2 5/16	3 3/16	11	17 3/8	15/32
21/32	1	1 1/16	85.8	7 3/4	3 7/8	1 19/32	2 5/16	3 3/16	11	17 3/8	1/2
11/16	1 1/8	1 3/16	84.7	7 3/4	3 7/8	1 25/32	2 5/16	3 9/16	11 3/4	18 7/8	17/32
23/32	1 1/8	1 3/16	84.5	7 3/4	3 7/8	1 25/32	2 5/16	3 9/16	11 3/4	18 7/8	17/32
3/4	1 1/8	1 3/16	84.1	7 7/8	3 15/16	1 25/32	2 3/8	3 9/16	11 7/8	19	9/16
25/32	1 1/8	1 3/16	83.6	7 7/8	3 15/16	1 25/32	2 3/8	3 9/16	11 7/8	19	19/32
13/16	1 1/4	1 5/16	82.8	7 7/8	3 15/16	1 31/32	2 3/8	3 15/16	12 5/8	20 1/2	5/8
27/32	1 1/4	1 5/16	82.2	7 7/8	3 15/16	1 31/32	2 3/8	3 15/16	12 5/8	20 1/2	5/8
7/8	1 1/4	1 5/16	82.5	8 1/4	4 1/8	1 31/32	2 1/2	3 15/16	12 7/8	20 3/4	21/32
29/32	1 1/4	1 5/16	82.0	8 1/4	4 1/8	1 31/32	2 1/2	3 15/16	12 7/8	20 3/4	11/16
15/16	1 3/8	1 7/16	81.7	8 1/2	4 1/4	2 5/32	2 9/16	4 5/16	13 3/4	22 3/8	23/32
31/32	1 3/8	1 7/16	81.5	8 5/8	4 5/16	2 5/32	2 5/8	4 5/16	13 7/8	22 1/2	3/4
1	1 3/8	1 7/16	81.0	8 5/8	4 5/16	2 5/32	2 5/8	4 5/16	13 7/8	22 1/2	3/4
*1 1/32	1 3/8	1 7/16	80.6	8 5/8	4 5/16	2 5/32	2 5/8	4 5/16	13 7/8	22 1/2	25/32
*1 1/16	1 3/8	1 7/16	80.1	8 5/8	4 5/16	2 5/32	2 5/8	4 5/16	13 7/8	22 1/2	25/32
*1 3/32	1 3/8	1 7/16	80.0	8 3/4	4 3/8	2 5/32	2 5/8	4 5/16	13 7/8	22 1/2	13/16
*1 1/8	1 1/2	1 9/16	79.1	8 3/4	4 3/8	2 11/32	2 11/16	4 11/16	14 3/4	24 1/8	27/32

NOTE.—All but Items marked (*) Designed and Recommended by Hartford Stm. Blr. Insp. and Ins. Co

QUADRUPLE RIVETED BUTT JOINTS



T. S.—55,000 lbs. Single S. S.—42,000 lbs. C. S.—95,000 lbs. Double S. S.—78,000 lbs

Thick. of Straps "T" Inches	Diameter of Cold Rivet Inches	Max. Dia. of Rivet Hole Inches	Efficiency in Per Cent	Long Pitch "L. P." Inches	Middle Pitch "M. P." In.	Short Pitch "S. P." In.	Gauge "A" Inches	Space "B" Inches	Space "C" Inches	Space "D" Inches	Width Outside Strap "E" Inches	Width Inside Strap "F" Inches	Thick. of Straps "t" Inches
1/4	1/2	9/16	94.3	10	5	2 1/2	27/32	1 11/16	1 11/16	1 5/8	6 3/4	13 3/8	3/16
* 9/32	1/2	9/16	94.3	10	5	2 1/2	27/32	1 11/16	1 11/16	1 5/8	6 3/4	13 3/8	3/16
9/32	9/16	5/8	94.3	11	5 1/2	2 3/4	15/16	1 13/16	1 7/8	1 3/4	7 3/8	14 5/8	3/16
5/16	11/16	3/4	94.6	14	7	3 1/2	1 1/8	2 1/8	2 1/4	2	8 3/4	17 1/4	1/4
11/32	11/16	3/4	94.2	14	7	3 1/2	1 1/8	2 1/8	2 1/4	2	8 3/4	17 1/4	1/4
3/8	11/16	3/4	93.3	14	7	3 1/2	1 1/8	2 1/8	2 1/4	2	8 3/4	17 1/4	5/16
* 13/32	3/4	13/16	94.3	14 3/8	7 3/16	3 19/32	1 7/32	2 1/8	2 7/16	2 1/8	9 1/8	18 1/4	5/16
13/32	13/16	7/8	94.0	14 5/8	7 5/16	3 21/32	1 5/16	2 3/16	2 5/8	2 1/4	9 5/8	19 3/8	5/16
7/16	13/16	7/8	94.1	15	7 1/2	3 3/4	1 5/16	2 1/4	2 5/8	2 1/4	9 3/4	19 1/2	3/8
* 7/16	7/8	15/16	94.0	15 5/8	7 13/16	3 29/32	1 13/32	2 11/32	2 13/16	2 3/8	10 5/16	20 11/16	3/8
15/32	7/8	15/16	94.0	15 5/8	7 13/16	3 29/32	1 13/32	2 11/32	2 13/16	2 3/8	10 5/16	20 11/16	3/8
1/2	7/8	15/16	94.0	15 5/8	7 13/16	3 29/32	1 13/32	2 11/32	2 13/16	2 3/8	10 5/16	20 11/16	3/8
17/32	7/8	15/16	94.0	15 5/8	7 13/16	3 29/32	1 13/32	2 11/32	2 13/16	2 3/8	10 5/16	20 11/16	13/32
9/16	7/8	15/16	94.0	15 11/16	7 21/32	3 59/64	1 13/32	2 11/32	2 13/16	2 3/8	10 5/16	20 11/16	7/16
19/32	1	1 1/16	93.1	15 1/2	7 3/4	3 7/8	1 19/32	2 5/16	3 3/16	2 5/8	11	22 5/8	7/16
5/8	1	1 1/16	93.1	15 1/2	7 3/4	3 7/8	1 19/32	2 5/16	3 3/16	2 5/8	11	22 5/8	15/32
21/32	1	1 1/16	92.5	15 1/2	7 3/4	3 7/8	1 19/32	2 5/16	3 3/16	2 5/8	11	22 5/8	1/2
11/16	1 1/8	1 3/16	92.4	15 5/8	7 13/16	3 29/32	1 25/32	2 11/32	3 9/16	2 7/8	11 13/16	24 11/16	17/32
23/32	1 1/8	1 3/16	92.1	15 1/2	7 3/4	3 7/8	1 25/32	2 5/16	3 9/16	2 7/8	11 3/4	24 5/8	17/32
3/4	1 1/8	1 3/16	91.1	15 1/2	7 3/4	3 7/8	1 25/32	2 5/16	3 9/16	2 7/8	11 3/4	24 5/8	9/16
25/32	1 1/8	1 3/16	90.3	15 1/2	7 3/4	3 7/8	1 25/32	2 5/16	3 9/16	2 7/8	11 3/4	24 5/8	19/32
13/16	1 1/4	1 5/16	90.8	15 5/8	7 13/16	3 29/32	1 31/32	2 11/32	3 15/16	3 1/8	12 9/16	26 11/16	5/8
27/32	1 1/4	1 5/16	89.9	15 5/8	7 13/16	3 29/32	1 31/32	2 11/32	3 15/16	3 1/8	12 9/16	26 11/16	5/8
7/8	1 1/4	1 5/16	89.1	15 3/4	7 7/8	3 15/16	1 31/32	2 3/8	3 15/16	3 1/8	12 5/8	26 3/4	21/32
29/32	1 1/4	1 5/16	88.3	15 3/4	7 7/8	3 15/16	1 31/32	2 3/8	3 15/16	3 1/8	12 5/8	26 3/4	11/16
15/16	1 1/4	1 5/16	87.8	16	8	4	1 31/32	2 13/32	3 15/16	3 1/8	12 11/16	26 13/16	23/32
31/32	1 1/4	1 5/16	87.1	16	8	4	1 31/32	2 13/32	3 15/16	3 1/8	12 11/16	26 13/16	3/4
1	1 3/8	1 7/16	87.3	16	8	4	2 5/32	2 13/32	4 5/16	3 3/8	13 7/16	28 13/16	3/4
1 1/32	1 3/8	1 7/16	86.5	16	8	4	2 5/32	2 13/32	4 5/16	3 3/8	13 7/16	28 13/16	25/32
1 1/16	1 3/8	1 7/16	86.3	16 1/2	8 1/4	4 1/8	2 5/32	2 15/32	4 5/16	3 3/8	13 9/16	28 15/16	25/32
1 3/32	1 3/8	1 7/16	85.9	16 3/4	8 3/8	4 3/16	2 5/32	2 1/2	4 5/16	3 3/8	13 5/8	29	13/16
1 1/8	1 3/8	1 7/16	85.4	16 3/4	8 3/8	4 3/16	2 5/32	2 1/2	4 5/16	3 3/8	13 5/8	29	27/32
1 5/32	1 3/8	1 7/16	84.8	16 3/4	8 3/8	4 3/16	2 5/32	2 1/2	4 5/16	3 3/8	13 5/8	29	7/8
1 3/16	1 3/8	1 7/16	84.5	17	8 1/2	4 1/4	2 5/32	2 9/16	4 5/16	3 3/8	13 3/4	29 1/8	7/8
1 7/32	1 1/2	1 9/16	84.4	17	8 1/2	4 1/4	2 11/32	2 9/16	4 11/16	3 5/8	14 1/2	31 1/8	29/32
1 1/4	1 1/2	1 9/16	84.0	17 1/8	8 9/16	4 9/32	2 11/32	2 9/16	4 11/16	3 5/8	14 1/2	31 1/8	15/16

NOTE.—All but Items marked (*) Designed and Recommended by Hartford Stm. Blr. Insp. and Ins. Co.

Standard Number of Rivets in Single Riveted Circular Seams

Thickness of Plate	$\frac{3}{16}''$	¼″	$\frac{5}{16}''$	⅜″	$\frac{7}{16}''$	½″
Dia. of Rivets	½″	⅝″	¾″	⅞″	1″	1″
Dia. of Pipe	Number of Rivets					
18″	36	28	28	24	20	24
19″	36	32	28	24	24	24
20″	40	32	28	28	24	24
21″	40	36	32	28	24	28
22″	44	36	32	28	28	28
23″	44	40	36	32	28	28
24″	48	40	36	32	28	32
25″	48	40	36	32	28	32
26″	52	44	40	36	32	32
27″	52	48	40	36	32	36
28″	56	48	40	36	32	36
29″	56	48	44	40	36	36
30″	60	52	44	40	36	40
31″	60	52	48	40	36	40
32″	60	52	48	44	40	40
33″	64	56	48	44	40	40
34″	64	56	52	44	40	44
35″	68	60	52	48	44	44
36″	68	60	52	48	44	44
37″	72	64	56	48	44	48
38″	72	64	56	52	44	48
39″	76	64	60	52	48	48
40″	76	68	60	52	48	52
41″	80	68	60	56	48	52
42″	80	72	64	56	52	52
43″	84	72	64	56	52	56
44″	84	76	68	60	52	56
45″	88	76	68	60	56	56
46″	88	80	68	60	56	60
47″	92	80	72	64	56	60
48″	92	80	72	64	60	60
49″	96	84	72	64	60	64
50″	96	84	76	68	60	64
51″	100	88	76	68	60	64
52″	100	88	80	68	64	68
53″	104	92	80	72	64	68
54″	104	92	80	72	64	68
55″	108	92	84	72	68	72
56″	108	96	84	76	68	72
57″	112	96	84	76	68	72
58″	112	100	88	76	72	76
59″	116	100	88	80	72	76
60″	116	100	88	80	72	76
61″	120	104	92	80	76	80
62″	120	104	92	84	76	80
63″	124	108	96	84	76	80
64″	124	108	96	84	76	84
65″	128	108	96	88	80	84
66″	128	112	100	88	80	84
67″	132	112	100	88	80	84
68″	132	116	104	92	84	88
69″	136	116	104	92	84	88
70″	136	120	104	96	84	88
71″	140	120	108	96	88	92
72″	140	120	108	96	88	92

SHEARING AND BEARING VALUE OF RIVETS

Unless special values are called for by city building ordinances, it is customary to use a
Shearing value of 12,000 pounds per square inch for Shop Rivets,
Shearing value of 10,000 pounds per square inch for Field Rivets.

Diameter of Rivet, Inches	Area, Square Inches	Single Shear at 7,500 Pounds	Bearing Value in Pounds for Different Thickness of Plate in Inches at 15,000 Pounds per Square Inch												
			1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1
3/8	.1104	830	1410	1760	2110	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1/2	.1963	1470	1880	2340	2810	3280	3750	.....	.....	.....	.....	.....	.....	.....	.....
5/8	.3068	2300	2340	2930	3520	4100	4690	5280	5860	.....	.....	.....	.....	.....	.....
3/4	.4418	3310	2810	3520	4220	4920	5630	6330	7030	7720	8440	.....	.....	.....	.....
7/8	.6013	4510	3280	4100	4920	5740	6560	7380	8200	9030	9850	10670	11480	12300	.....
1	.7854	5890	3750	4690	5620	6560	7500	8440	9380	10310	11250	12190	13130	14060	15000

Diameter of Rivet, Inches	Area, Square Inches	Single Shear at 9,000 Pounds	Bearing Value in Pounds for Different Thickness of Plate in Inches at 18,000 Pounds per Square Inch												
			1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1
3/8	.1104	990	1680	2110	2530	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1/2	.1963	1770	2250	2820	3370	3940	4500	.....	.....	.....	.....	.....	.....	.....	.....
5/8	.3068	2760	2790	3480	4180	4870	5580	6330	7030	.....	.....	.....	.....	.....	.....
3/4	.4418	3970	3370	4210	5050	5910	6750	7590	8440	9280	10130	.....	.....	.....	.....
7/8	.6013	5410	3940	4920	5910	6880	7870	8860	9840	10830	11810	12800	13780	14770	.....
1	.7854	7060	4500	5620	6750	7870	9000	10120	11250	12370	13500	14630	15750	16880	18000

SHEARING AND BEARING VALUE OF RIVETS—Continued

Diameter of Rivet, Inches	Area, Square Inches	Single Shear at 10,000 Pounds	Bearing Value in Pounds for Different Thickness of Plate in Inches at 20,000 Pounds per Square Inch												
			1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1
3/8	.1104	1100	1880	2340	2810	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1/2	.1963	1960	2500	3130	3750	4380	5000	.....	.....	.....	.....	.....	.....	.....	.....
5/8	.3068	3070	3130	3910	4690	5470	6250	7030	7810	.....	.....	.....	.....	.....	.....
3/4	.4418	4420	3750	4690	5630	6560	7500	8440	9380	10310	11250	.....	.....	.....	.....
7/8	.6013	6010	4380	5470	6570	7660	8750	9840	10940	12030	13130	14220	15310	16410	.....
1	.7854	7850	5000	6250	7500	8750	10000	11250	12500	13750	15000	16250	17500	18750	20000

Diameter of Rivet, Inches	Area, Square Inches	Single Shear at 12,000 Pounds	Bearing Value in Pounds for Different Thickness of Plate in Inches at 24,000 Pounds per Square Inch												
			1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1
3/8	.1104	1320	2250	2810	3380	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1/2	.1963	2360	3000	3750	4500	5250	6000	.....	.....	.....	.....	.....	.....	.....	.....
5/8	.3068	3680	3750	4690	5630	6560	7500	8440	9380	.....	.....	.....	.....	.....	.....
3/4	.4418	5300	4500	5630	6750	7880	9000	10130	11250	12380	13500	.....	.....	.....	.....
7/8	.6013	7220	5250	6560	7880	9190	10500	11810	13130	14440	15750	17060	18380	.....	.....
1	.7854	9430	6000	7500	9000	10500	12000	13500	15000	16500	18000	19500	21000	22500	24000

Bearing values given above or to the right of the upper zigzag lines are greater than double shear.

Bearing values given between upper and lower zigzag lines are less than double shear and greater than single shear.

Bearing values given below or to the left of the lower zigzag lines are less than single shear.

Temperature Stresses. Under conditions in the northern states the temperature of water and consequently of the pipe will range from 32 to 75 or 80°F., or for average conditions the range is about 45°. The pipe must be held so that it will not move with expansion and contraction. Under these conditions the change in temperature, which tends to expand or contract the pipe, uses all its force in putting it under stress. The stresses thus produced may range from nothing at the lower temperature to the maximum amount in compression at the higher temperature, or from nothing at the higher temperature to the maximum amount in tension at the lower temperature, or they may be divided, coming partly in tension at the lower temperature and partly in compression at the higher temperature. This depends on the temperature at which the pipe is laid and finally connected up. Under the most unfavorable conditions the stresses produced by temperature in this climate are about 9000 lb. per sq. in., and as this comes well within the strength of the steel no difficulty is occasioned by them. Ordinarily they are less than this.

Anchorages are built to keep the pipe from moving at all free ends and at all sharp bends. These anchorages are formed by riveting angle irons to the steel pipe, usually four angles being attached to one 30-foot length, with a sufficient number of rivets to hold the temperature stresses, and these lengths of pipe are surrounded with concrete reinforced with steel rails of such a shape as to be capable of withstanding the computed amount of stress. In some lines anchorages have been omitted and expansion joints provided at all gates, ends, and other places when continuity of riveted connection cannot be maintained. The temperature push or pull on the anchorage in tons of 2000 lbs. for steel pipes of various diameters and thicknesses is shown in the last column of the table below.

DATA FOR STEEL PIPE

Diam. in inches	Thickness of plate in inches	Greatest allowable depth of cover in feet	Temperature stress in net tons	Diam. in inches	Thickness of plate in inches	Greatest allowable depth of cover in feet	Temperature stress in net tons	Diam. in inches	Thickness of plate in inches	Greatest allowable depth of cover in feet	Temperature stress in net tons
30	3/16	5	92		⅜	9	257		⅝	15	551
	¼	8	122		7/16	12	300	60	5/16	3	305
	5/16	12	152		½	16	343		⅜	4	366
	⅜	18	183	48	¼	3	196		7/16	6	430
	7/16	25	214		5/16	5	244		½	8	488
36	¼	5	147		⅜	7	293		⅝	12	612
	5/16	9	183		7/16	9	342	72	7/16	2	367
	⅜	12	220		½	12	391		⅜	3	440
	7/16	17	257	54	5/16	4	275		7/16	4	515
	½	22	294		⅜	6	330		½	6	588
42	¼	4	172		7/16	8	386		⅝	9	735
	5/16	6	214		½	10	441				

Fig. 39—VIEW SHOWING STIFFENER RINGS AND ANCHORAGE.

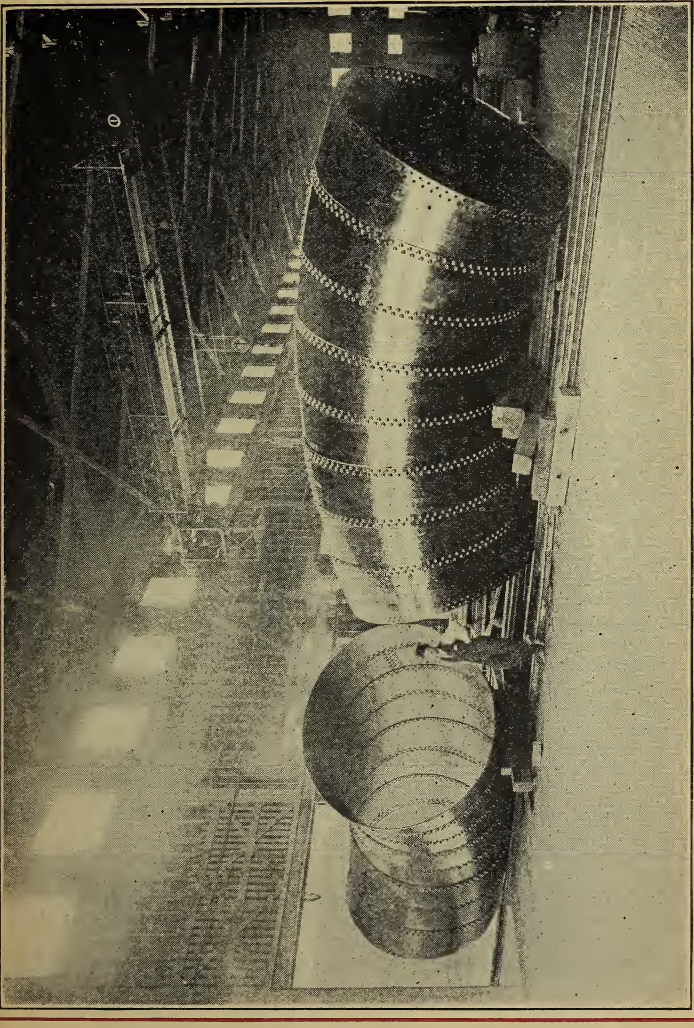


Fig. 40—DOUBLE RIVETED STEEL BENDS OF LARGE DIAMETER.

Bends in Steel Pipe are usually made by cutting off some of the plates at the joint. Both horizontal and vertical bends are made in the same way. It is easier to lay out the work if the horizontal and vertical bends are made in separate joints, but in case of need they can be combined.

The amount of bend that can be made in one joint depends upon the size and thickness of the plate. With $\frac{5}{16}$-inch plates bends up to 5° in one joint are easily made; with $\frac{3}{8}$-inch plates 4°, and with $\frac{7}{16}$-inch plates 3°. Sharper bends are made when necessary but it is harder to calk them tight. With crooked lines the lengths of pipe may be cut, one bend made every 15 ft. or every 7½ ft. With sharper bends special arrangements are made.

It is better to make all bends in steel pipe of steel plates riveted up, rather than of castings, and in case of sharp bends the pipe should be anchored on both sides, to carry the resultants of the temperature stresses.

SUPERIORITY OF LOCK-BAR PIPE

The usage of steel pipe increases in direct proportion to the working pressures and the necessity for uninterrupted service. An increasing tendency toward the use of steel pipe on distribution systems through city streets has been noticeable in recent years. On supply mains, gas lines, hydro-electric installations, etc., where such characteristics as dependability, flexibility and shock absorbing qualities are paramount, steel pipe is almost exclusively used.

From the severity of the specifications of materials and construction, and the complete and modern methods of fabrication of Lock-Bar Pipe it is evident that in no pipe works is greater precaution taken to safeguard the interests of the purchaser.

Unlike a great many manufactories, where iron is considered merely iron and steel is just steel, the Company's Engineers and Chemists are continually striving to insure that materials shall come up to specifications, and its supervisors, that workmanship shall conform to the exacting standards it has set. In a word quality is the dominant keynote and permeates the Company's entire organization. The product of this combined effort is passed on to the user of its water mains, and oil and gas lines in the confident belief that satisfactory service, over a period of many years, will ensue.

The elements which make for superiority are strength, carrying capacity, durability and cost.

STRENGTH

In-so-far as strength is concerned, LOCK-BAR STEEL PIPE outranks pipe of any other character, All steel pipe is stronger than cast iron pipe. The former is flexible, the latter brittle. As a result a blow which would break cast-iron pipe, merely dents steel pipe.

Wood stave pipe depends upon steel hoops or bands, which hold it together, for strength. More steel is required for the hoops or bands, than for a continuous plate, in pipe of equal strength.

The strength of steel pipe is equal to the strength of the longitudinal joints. Single riveted joints have an efficiency of 48% to 60%. Double riveted joints, 68% to 74%. Welded 90%. LOCK-BAR joints 100%.

Fig. 41—42″ x $\frac{7}{16}$″ "Lock-Bar" pipe tested to 1050 lbs. per sq. in. At this pressure the pipe was actually exceeding by 765 lbs. per sq. inch its normal working pressure. The metal of the plate was stretched over 4″ in circumference without injury to or leakage along the lock-bar joints. Owing to blowing out of riveted pads at gauge and inlet, tests at higher pressures were not possible.

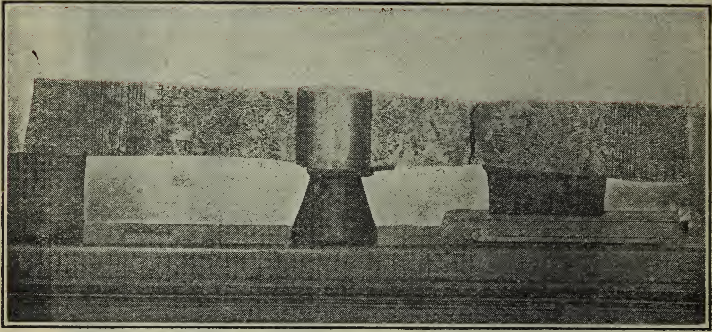


Fig. 42—STEEL PLATE BROKEN IN TEST WITHOUT INJURY TO LOCK-BAR JOINT.

TESTS

Many tests have been made to determine the fitness of LOCK-BAR Pipe. A few such cases are cited and photographs shown of actual test pieces.

Figure 42 is of interest in further showing the strength of the lock-bar joint over that of the steel plate itself. This is an actual section cut out of a pipe and was tested by pulling in an ordinary tension machine which broke the plate without opening the joints.

Fig. 43

Fig. 44

During January, 1919, W. J. Krefeod, Professor of Tests, Columbia University, New York City, N. Y., conducted several tests to determine the strength of Lock-Bar Pipe joints, with the following results. It is to be noted that during the tests, the steel plate .375 inches thick broke whereas the joint remained closed and tight.

In the sample of Lock-bar joints:

Marked—No. 1, 2, 3, 4

For test we find:

	1	2	3	4
Material	Steel			
Shape of test piece	Lock-Bar joint			
Width in inches	2.000	2.000	2.000	2.000
Thickness in inches	0.375	0.375	0.375	0.375
Area,sq. inches	0.750	0.750	0.750	0.750
Yield Point, lbs. actual load	......	26,760	26,630	27,660
Maximum actual load	43,240	43,250	42.740	43,330
Yield point, lbs. per sq. in	......	35,650	35,550	36,900
Ultimate strength, lbs. per sq. in	57,700	57,700	57,700	57,750
Distance of fracture from Joint, in	3¼	3¾	4¼	4¼

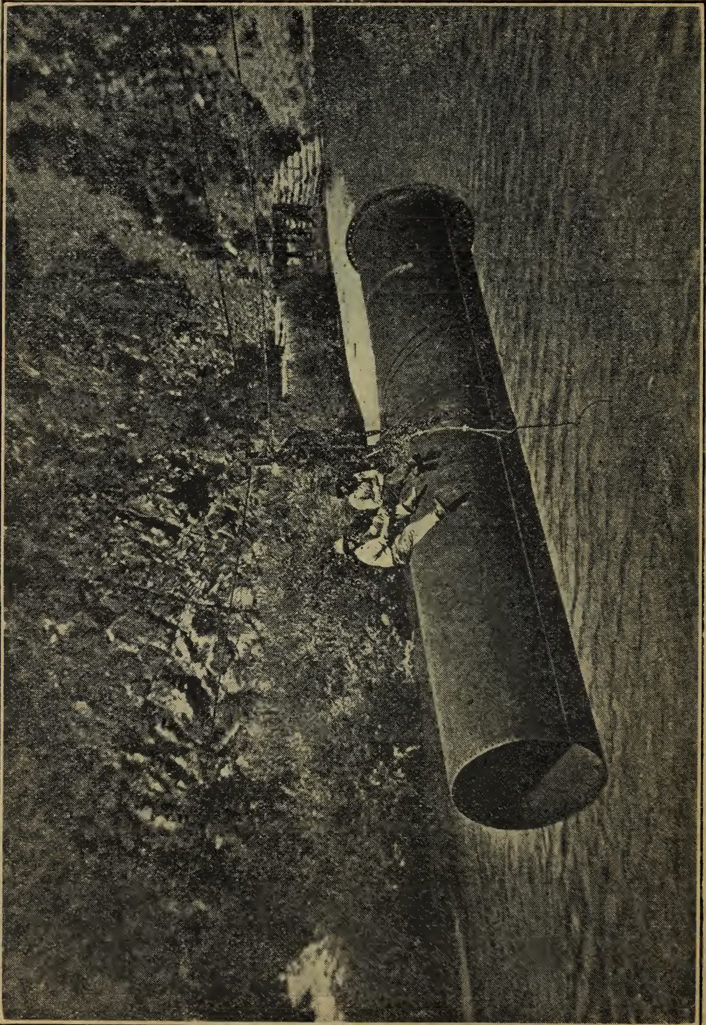


Fig. 45—ACROSS THE SOUTH PLATTE RIVER. DENVER UNION WATER WORKS.

CARRYING CAPACITY

In the determination of the relative advantages of different characters of conduits many elements must be considered.

For this purpose the following discussion, under the major heads, of "Friction," "Corrosion," "Cost," "Test," and "Testimony" is printed herewith.

Carrying Capacity of Steel Pipe. Lock-Bar steel pipe has a smooth interior unobstructed by rivets and has a slightly better carrying capacity than cast-iron pipe. Riveted pipe is less smooth in the interior, the projecting rivets increasing the friction of the flowing water, and also the numerous joints in the plates with either in-and-out joints or with taper joints. For these reasons riveted steel pipe carries from 10 to 15 percent less water than Lock-Bar pipe or cast-iron pipe. In comparing riveted pipe with Lock-Bar pipe and cast-iron pipe, a riveted pipe should be taken with a sufficiently greater diameter in order to carry as much water as the others.

The carrying capacity of pipes of the same diameter varies inversely with their frictional resistance. (See "Flow of water in pipes," page 123.)

LOCK-BAR STEEL PIPE has been held by eminent engineers, including among others, J. Waldo Smith, Clemens Herschel and Allen Hazen, to have ten to twenty percent less resistance than riveted steel pipe. Preliminary tests on 36,000 feet of thirty-six inch pipe at Montreal, Quebec, Canada, indicated a friction loss less than that given by Weston's tables for new cast-iron pipe.

It will be readily understood why "LOCK-BAR" pipe has so much more carrying capacity. Obstructions to flow, causing friction and reducing capacity are practically eliminated. The absence of obstruction and smooth inner surface further eliminates opportunity for the building up within the pipe of deposits to restrict the pipe area.

Cast-iron pipe on the other hand, often has a rough sandy surface and frequently presents a circular ribbed appearance due to the method of manufacture. The end joints are not always laid concentrically and in making a "curve in the pipe" without "specials," the interior of the joints are left open on the side, top or bottom. These conditions favor the growth of organisms upon the sides and top of the pipe and deposits upon the bottom. Riveted pipe is open, to some extent, to objections, due to the obstructions caused by rivet heads, but Lock-Bar pipe has but one fourth the number of circular seams that riveted pipe has and but 40% of the joints of a cast-iron pipe of 12 foot length. Moreover the smooth longitudinal seams have no rivets to furnish easy attachment for foreign matter and to create eddies and the resultant friction and loss of head.

CORROSION

Numberless discussions have taken place as to the relative life of steel, wrought-iron and cast-iron pipe, in-so-far as corrosion affects durability. One of the strongest arguments in favor of steel pipe over wrought iron, in this respect, which has come to our notice within recent years, aside from the actual testimony of installations, is that presented by one of the best known seamless tube and small pipe manufacturers in the country, in their abandonment of charcoal and puddled iron for steel tubes, in 1909. We quote from this testimony as follows: "The use of steel for welded pipe was made possible, in the first place, through the manufacture by ———of a special grade of low carbon steel, ———. Steel pipe has in later years superseded wrought-iron pipe by proving its superiority in strength, ductility, and finally, as made under modern processes, by its superior durability.

"As manufacturers of both wrought-iron and steel pipe for many years, we have had a special interest in this question of durability, about which there has been so much debate, and with our dual interest have had exceptional opportunities to make comparison of these materials under all manner of service. Moreover, we have frequently shipped a wrought-iron coupling on steel pipe, so that in case of any external corrosion, a comparison of the two materials could be readily made under the same conditions. As a result of an extended study of this question in the laboratory and in the field, and with the experience of many large consumers of pipe, who have made careful observations from cases where both iron and steel pipe were used under the same conditions, there was no further room for doubt as to the advantage of steel pipe,———, in respect to its resistance to corrosion, particularly as to pitting———."

CAUSE OF CORROSION

There is considerable difference of opinion on this particular phase of the subject, but never-the-less the following is given, as a condensed survey of a few underlying facts, which have been established by experiment.

We quote from a recent authority on the subject: "It is claimed by some who have studied the problem that corrosion is due to 'differences' of electrolytic potential between two adjacent places on the surface of the metal, resulting in pitting. This difference may be due to lack of homogeneity in the metal, but, it is believed, more often is caused by foreign matter electro-negative to iron, attached to the surface; such as mill scale, carbon or rust itself. It has been clearly established that corrosion consists of two main reactions, namely; the solution of a small part of the iron in water, and the subsequent oxidation of the ferrous iron in solution to ferric hydroxide, which is then precipitated out as 'rust.' The amount of the corrosion is still further increased by the combination of free oxygen with the hydrogen, which was deposited on the surface of the metal when iron went into solution. This cycle of reactions is repeated, and the 'rust'

continues to accumulate so long as both water and air are present. Other agencies may accelerate the process of corrosion, but in the absence of either one of these elements, no corrosion can take place. Steel will remain clean and bright for an indefinite period in dry air, and also in water that is free from air. Hence the necessity to see to it that, ———iron and steel ———are protected by impervious and durable coatings."

The late Prof. F. L. Kortright says, "The rusting of iron or steel is caused by the combined action of water (condensed on the metal), carbon dioxide (or some other volatile acid), and oxygen, and the presence of certain salts increases the rapidity of action. The effect of the substances seems to be, first, the formation of ferrous carbonate, then ferrous bicarbonate and this is broken down into magnetic oxide of iron (giving off the carbon dioxide which acts on more iron to form ferrous carbonate), and the magnetic oxide is finally oxidized to hydrated ferric oxide which is the ordinary condition in which rust exists."

Fig. 46

STEEL Vs. CAST-IRON PIPES

The Coolgardie pipe line, which was a 30″ steel pipe main installed in Coolgardie, Australia, in 1900, is frequently referred to by certain interests as an example of a failure of steel pipe. In the evidence of the various experts appointed by the Commission to investigate the troubles attending the Coolgardie pipe line many interesting facts were disclosed. The water supply itself was found to contain 26 parts of sodium cloride and 5 parts of magnesium cloride per 100,000. The report states "It is to be expected that such a water would possess more than usual corrosive action upon iron or steel."

With regard to the external corrosion, the report states "The sandy soil along this pipe line is so impregnated with salt that in many places it

absolutely glistens, in which case it is hardly surprising that external corrosion set in. The main is seriously corroded over a portion of its length which had been coated with a special solution applied at a low temperature; so low, in fact, that under the burning sun of West Australia it was found that the coating ran off the pipes before they were laid. For this reason this particular coating was abandoned and a harder coating subsequently used. Unfortunately the benefit of this hard coating was largely neutralized as some of the pipes were exposed to the sun for two years before they were laid. On inspection it was found that wherever the pipe line was sufficiently coated, despite these corrosive surroundings, was practically in as good a state of preservation as when laid. Had the pipes been laid above ground as recommended by the Commission the external corrosion as caused by the soluble salts contained in the soil would have been entirely done away with.

Extract from "Civil Engineering," April 1912:

"Evidence of any local failure of either cast-iron or steel pipes is of little value when comparing the two metals unless one has evidence of the behaviour of both under similar conditions. Fortunately, in the case of the West Australia Pipes (Coolgardie) there is ample evidence on both sides.

In this district a 12-in. cast-iron main was laid in 1890. This gave considerable trouble, so that when an increased supply was required in 1897, a 21-in. steel main was laid, and this has proved highly satisfactory.

The Perth supply (delivered by a 12-in. cast-iron and a 21-in. steel main) contains about 12 grains per gallon of these corrosive compounds. Eight years ago the cast iron main was so corroded that scraping from end to end was necessary, and five years later this process had to be repeated.

"The illustration, (fig.46), which was taken at random, shows the appearance of one of these pipes after five years' corrosion. The nodules of rust were found to be from 2 in. to 3 in. thick, and covered the entire inner surface of the pipe. On removal, the metal surface of the pipe appeared to be unaffected. On investigation, however, it was found that it could be cut into with a knife, and a soft black mass $\frac{3}{16}$ in. thick was removed. Under this the true metallic surface was found to be extensively and irregularly corroded.

"A section of the 21-in. steel main was removed for examination after eleven years' use. The coating of this pipe was in good order, being dark and lustrous, and showed very little evidence of decay. The surface of the coating was covered with a very thin film of brown earthy sediment, which, however, was not sufficiently thick to hide the coating.

"In comparing cast-iron and steel pipes it is desirable to further study Australian experience. The facts are that, while under exceptionally unfavorable conditions the Coolgardie main has given some trouble, the local experts know by bitter experience that cast-iron would have given much more. All the other leading centers throughout Australasia— Melbourne, Sydney, Adelaide, Perth, Brisbane, Auckland, Wellington, and a number of others—are supplied with steel water mains which, one and all, have

proved unqualified successes. The original Melbourne wrought water mains, 58 miles long and varying in diameter from 32 in. to 53 in. were laid in 1884. According to recent advice from the Inspector-General of Works in Melbourne, these mains are in as good preservation as when laid. The same condition prevails in other smaller mains installed there since. *One*—a 24-in. *main—laid in* 1887 *is particularly interesting in that it affords a direct comparison with cast-iron.*

The engineer wrote, with regard to this main:

" 'Some alterations in this main necessitated cutting out a length, including a 12-in. cast-iron branch nipple. This I found to be an advantage, as it afforded me a welcome opportunity of examining the plates in several places. Inside the pipe is now as if it had just come out of the (tube) works, so perfect and japan-like is the coating, and, making allowance for the adhering clay, the same may be said of the outside. This is the more remarkable from the fact that, in an equal period, a cast-iron pipe of equal diameter would have lost at least 1 in., and more probably 2 in., of section from corrosion. The cast-iron branch which had been connected to this wrought-iron pipe, with its valve, were heavily covered with material adhering to the inner surface in the form of nodules, and consisting of oxide of iron and earthy matter attracted to it. This deposit or incrustation is peculiar to all cast-iron pipes, large and small, in the Melbourne water-supply system. Its rate of growth is equal to the complete filling up of a 4-in. pipe in from 15 to 18 years.'

"Profiting by the success of steel pipes in Australasia, other countries have followed suit. Eighteen years ago Durban (South Africa) laid an 18-in. water-supply main of steel which proved so successful that two years ago they again ordered another large steel main. Monte Video, after experience of cast-iron, duplicated their existing main with one of steel, 30-in. in diameter and 30 miles long. Fifteen years ago Bradford (Yorkshire) laid two 36-in. water-supply mains which have proved an unqualified success. Some years ago the Leeds Municipal authorities, having in view the experience of Bradford, laid 24 miles of 33-in. steel pipes for a water supply. In Leeds neighbourhood there are well preserved samples of wrought-iron pipes which have been in the ground from fifty to sixty years. Other towns in Great Britain which have laid steel mains during recent years are Manchester, Swansea, Cardiff and many smaller towns. All the leading centres of population throughout South Africa have *adopted steel water mains, some of which have been in successful operation for over twenty years.*

"Probably the best evidence of the successful application of steel pipes is the rapidly increasing demand for them in all parts of the world in recent years.

Relative Corrosion of Wrought Iron and Steel. (H. M. Howe, *Proc. A. S. T. M.*, 1906.)—On one hand we have the very general opinion that steel corrodes very much faster than wrought-iron, an opinion held

so widely and so strongly that it cannot be ignored. On the other hand we have the results of direct experiments by a great many observers, in different countries and under widely differing conditions; and these results tend to show that there is no very great difference between the corrosion of steel and wrought-iron. Under certain conditions steel seems to rust a little faster than wrought-iron, and under others wrought-iron seems to rust a little faster than steel. Taking the tests in unconfined sea water as a whole wrought-iron does constantly a little better than steel, and its advantage seems to be still greater in the case of boiling sea water. In the few tests in alkaline water wrought-iron seems to have the advantage over steel, whereas in acidulated water steel seems to rust more slowly than wrought-iron.

Steel which in the first few months may rust faster than wrought-iron may, on greatly prolonging the experiments, or pushing them to destruction, actually rust more slowly, and *vice versa.*

Carelessly made steel, containing blowholes, may rust faster than wrought-iron, yet carefully made steel, free from blowholes, may rust more slowly. Any difference between the two may be due not to the inherent and intrinsic nature of the material, but to defects to which it is subject if carelessly made. Care in manufacture, and special steps to lessen the tendency to rust, might well make steel less corrodible than wrought-iron, even if steel carelessly made should really prove more corrodible than wrought iron.

For extensive discussions on this subject see *Trans. A. I. M. E*...1905. *Proc. A. S. T. M.*, 1906 and 1908, and Bulletins of National Tube Co.

Corrosion of Iron and Steel.—Experiments made at the Riverside Iron Works, Wheeling, W. Va., on the comparative liability to rust of iron and soft Bessemer steel: A piece of iron plate and a similar piece of steel, both clean and bright, were placed in a mixture of yellow loam and sand, with which had been thoroughly incorporated some carbonate of soda, nitrate of soda, ammonium chloride, and chloride of magnesium. The earth as prepared was kept moist. At the end of 33 days the pieces of metal were taken out, cleaned, and weighed, when the iron was found to have lost 0.84% of its weight and the steel 0.72%. The pieces were replaced and after 28 days weighed again, when the iron was found to have lost 2.06% of its original weight and the steel 1.79%. (*Eng'g*, June 26, 1891.)

* ELECTROLYSIS

Electrolysis in Cast-iron Pipes is caused by stray return currents of electricity from various sources, especially from trolley car lines. These stray currents find their way into water pipes through the soil or through service pipes or hydrant connections or gas pipes or telephone conduits or any other metallic structures coming in contact with the water pipes or the services connected with them. Such currents flow in the pipes, leaving them at points near the power stations, or go through other metallic conductors to the power station.

Destruction of a Pipe by electrolysis occurs in two ways: (1) By a current collected by the pipe, following it for a distance and then leaving it in moist soil, the electrolysis occurring at the point where the current leaves the pipe. (2) By the flow of electricity in the pipe, a part of which leaves the pipe at lead joints or other points of extra resistance, coming back into the next length of pipe. These two kinds of electrolysis, while having the same effect on the pipe, are to be sharply distinguished. Electrolysis of the first kind may be corrected in great measure by connecting the pipe system with the negative poles of the dynamos at all power stations. This has the effect of taking the return current out of the pipes directly through a copper wire and avoiding the necessity of currents leaving the pipe in moist ground on the return journey. This method of treating the electrolysis question was proposed in the early days of electrolysis and used to a considerable extent. The principal objection to it is that it produces electrolysis of the second kind. This system is openly followed in some works, and is actually followed by unknown and indirect connections in others.

In cast-iron pipe lines the lead joint is a point of high resistance. The temperature of the melted lead is not sufficient to burn off the tar coating, and actual metallic connection is not made in all cases. The electric current goes through the soil around the joint in sufficient quantity to produce electrolysis on one side of the joint. This takes place in wet soil only. Dry soil is a non-conductor. When electricity makes a passage it goes through the water contained in the pores of the soil, and not through the soil particles. Water is a non-conductor, but it becomes a conductor when mineral substances are dissolved in it.

Electrolysis of the interior of pipes is extremely rare, because the water used for public water supply is not sufficiently mineralized to act as a conductor. If the water in the soil outside the pipe were equally pure from an electrolytic standpoint there would presumably be little trouble from this kind of electrolysis.

Electrolysis occurs because the ground water contains mineral matter and salts which increase its conductivity. The mineral matters in ground water may result from many sources, among them: (1) From cesspools and

*Merriman Third Edition

similar sources, which are known to increase the chlorine contents of ground water to from 10 to 100 times the natural amounts, in villages and cities, and to less extent in rural districts, (2) Urine of horses falling on public roads, (3) Sea water brought by the rain, this being a matter of importance only when pipes are not very far from the ocean, (4) Solution of mineral matters from the soil.

Insulation Joints are joints made of some non-conducting material to prevent the flow of electricity in pipes. Such joints have been made by driving wooden wedges between the spigot and bell of the cast-iron pipe in place of the lead. To be effective they must be repeated at short intervals, as the electric current will jump a number of such joints, passing through the surrounding moist soil and causing electrolysis at each of them.

Electrolysis of Steel Pipe. The riveted joints of steel pipe are almost perfect conductors of electricity. There is no evidence that a current flowing in a steel pipe injures it in any way as long as it does not leave the pipe. An electric current flowing in steel pipe and leaving it results in electrolysis at the point where it leaves the pipe.

Fig. 47—EFFECT OF ELECTROLYSIS ON CAST IRON PIPE—SPECIMEN NO. 1.

Fig. 48—SHOWING EFFECT OF ELECTROLYSIS ON CAST IRON PIPE—SPECIMEN NO. 2.

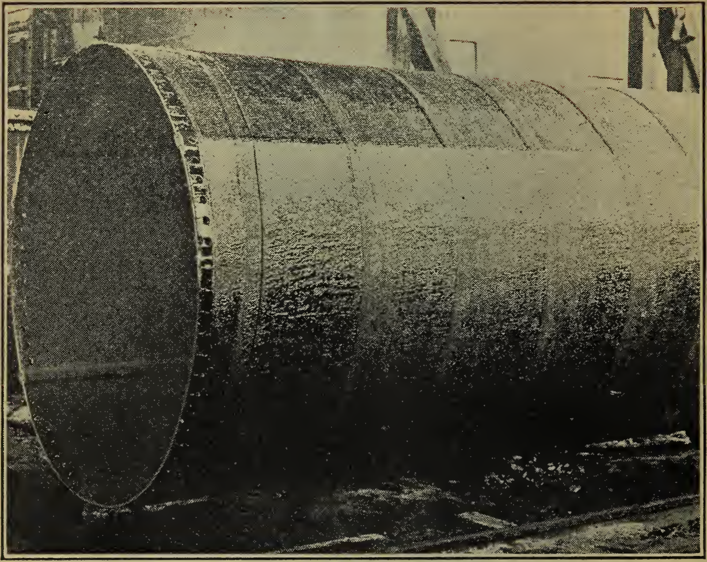


Fig. 49

INSULATING WRAPPINGS

As a further protection to the pipe coating this Company is prepared to furnish its pipe with a special coating of impregnated burlap (Figure 49), put on by a process developed in our works. It will be obvious that greater mechanical strength is lent to the protective coatings against abrasion during transportation and installation. The effective thickness of protection is also cheaply increased.

This process is as follows: The pipes are dipped in the regular pipe coating as usual and, after this coat has set, they are sent to a wrapping machine in which the pipes are slowly rotated on centers. A reel carrying a roll of 10-oz. Calcutta burlap, cut into strips 18″ wide, is placed on a carriage which travels lengthwise of the machine during the rotation of the pipe. As the carriage travels and the burlap is unwound from the reel by the revolving pipe, it is drawn through a tank containing a hot solution of mineral-rubber pipe coating and wound spirally on the pipe, the burlap being lapped upon itself to about the width of an inch. The tension of the burlap while winding is sufficient to cause it to lap close and snug on the pipe, without straining or tearing it.

The wrapping is kept back from the ends of the pipe sufficiently far to clear the rivet holes and not interfere with the making of the field joints. After the pipe is laid, riveted, caulked and tested, the field joints are wrapped with one wind of the burlap which has been immersed in field coating.

The following are some of the installations of LOCK-BAR Pipe wrapped in this manner:

City of Winnipeg	42,256 ft.—36″ x ¼″
" " Minneapolis	10,000 ft.—48″ x $\frac{5}{16}$″
" " " "	13,000 ft.—48″ x diff. thicknesses
" " " "	16,000 ft.—54″ x $\frac{5}{16}$″ to $\frac{7}{16}$″
" " Montreal	377 ft.—36″ x ⅜″
" " Winnipeg	24,000 ft.—36″ x ¼″
" " Rutland, Vt	631 ft.—54″ x $\frac{5}{16}$″
Dill & Collins	733 ft.—36″ x ⅜″
Brooklyn, N. Y.	5,000 ft.—66″ x ½″

TABLE OF QUANTITIES

The following Coating tables for Cast Iron and Steel and Wrought Iron Pipe indicate that the former require more Coating per square foot of pipe surface than either Steel or Wrought Iron Pipe, due mainly to the irregular surface of Cast Iron Pipe.

CAST-IRON PIPE
Coated Inside and Outside

	Running Feet per Ton	Pounds Coating per 100 Feet	Running Feet per Ton	Pounds Coating per 100 Feet
Kind of Pipe	Cast Iron	Cast Iron	Cast Iron	Cast Iron
Thickness of Coating	$\frac{1}{32}''$	$\frac{1}{32}''$	$\frac{1}{16}''$	$\frac{1}{16}''$
Diameter				
20″	1096	182	548	365
24″	908	220	454	440
30″	724	270	362	539
36″	607	329	303	659
42″	519	385	259	771
48″	455	440	227	879
54″	404	495	202	990
60″	365	548	182	1096
72″	302	662	151	1324
84″	259	772	129	1544

TABLE OF QUANTITIES

STEEL AND WROUGHT-IRON PIPE
Coated Inside and Outside

	Running Feet per Ton	Pounds Coating per 100 Feet	Running Feet per Ton	Pounds Coating per 100 Feet
Kind of Pipe	Steel	Steel	Steel	Steel
Thickness of Coating	$\frac{1}{32}''$	$\frac{1}{32}''$	$\frac{1}{16}''$	$\frac{1}{16}''$
Diameter				
20″	1164	172	582	344
24″	969	206	484	423
30″	774	258	387	517
36″	645	310	322	621
42″	553	361	276	723
48″	484	413	242	826
54″	430	465	215	930
60″	387	517	193	1034
72″	323	619	161	1238
84″	276	724	138	1449

The above tables have been made from the figures of practical experience and all allowances have been made for waste and other losses.

These figures can therefore be safely taken as a basis for estimate of quantities under all ordinary conditions.

*BIBLIOGRAPHY for those wishing to follow up the discussion of the subject regarding the relative corrosion of iron and steel.

Proceedings of Engineers' Society of Western Pennsylvania, 1907

T. N. Thomson, two reports, 1908-1910 American Society of Heating and Ventilating Engineers

American Society for Testing Materials, 1906, 1908 (Howe)

"Corrosion of Iron," A. Sang (McGraw-Hill Publishing Co.) (Extensive bibliographs)

"Corrosion and Preservation of Iron and Steel," A. S. Cushman and Hy. A. Gardner (McGraw-Hill Publishing Co.)

"Metallurgy of Iron and Steel," Bradley Stoughton

"Electrolytic Theory of the Corrosion of Iron and its Applications," Wm. H. Walker (Journal, Iron and Steel Institute, 1909)

"Function of Oxygen in the Corrosion of Metals," Wm. H. Walker (Transactions American Electrochemical Society, Vol. 14, p. 175)

"Corrosion of Iron and Steel," by J. N. Friend, 1911 (Longmans, Green and Company)

"Relative Corrosion of Wrought-Iron and Steel," Henry M. Howe, (Mineral Industry, V. 4, p. 429)

"Puddled Iron Versus Steel," Frank N. Speller, (Iron Age, V. 75, p. 1666, 1881)

"Corrosion of Iron and Steel," Frank N. Speller, (Iron Age V. 79, p. 478)

"Corrosion of Pipe in Coal Mines" (Iron Age, V. 78, p. 80)

"Steel Plate Pipe Conduit II—Rochester Water Works, Rochester, N. Y.

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*National Pipe Standards

COST OF STEEL PIPES

Steel pipe is generally cheaper than cast-iron pipe in sizes of 24″ and upwards, the difference in cost increasing with ascending pressure conditions. The long 30 ft. lengths involve less field joints and bell holes and the fact that it is lighter to handle and transport, makes the cost of installation considerably cheaper than that of cast-iron pipe.

Consideration should also be given to the fact that likewise replacement and repair, costs less with steel pipe.

The usually lower cost of steel pipe over cast-iron and other classes of pipe, effects an initial saving, which, together with the interest it will earn over a period of years, is usually enough not only to maintain the line in proper repair for life, but also to provide a sinking fund which will eventually replace it.

Rochester, N. Y. in 1873-4 laid 9.6 miles of 36″ and 3 miles of 24″ W. I. pipe $\frac{3}{16}$″ thick with c. i. bell and spigot lead joints. The pipe is still in continuous service. In 1893-4 the city laid a second conduit consisting of 26½ miles of 38″ riveted steel pipe ¼″ to ⅜″ thick. Its condition has been carefully studied by the City Engineer's Department. Each pit hole has been located. They are all from the outside, due to inefficient coating. Within the last four years the city has laid about 19 miles (Conduit No. 3) of 37″ Lock-Bar steel pipe ¼″ thick in competition with cast-iron. With improved methods of coating, effective protection is expected. Even after a considerable portion of Conduit II has been recoated on the outside, the conduit is considered a more economical proposition than Cast-Iron would have been.

LEAKAGE OF LEADED JOINTS

American Civil Engineers' Handbook 1911 (edited by Mansfield Merriman) Page 956: "It is impossible to keep lead joints permanently tight—the expansion and contraction from temperature changes are accompanied by a slight slipping of lead at each joint—settlements cause movements in the joints."

Page 956:

"With well tested work under average conditions a leakage of 3 gallons per 24 hours per lineal foot of lead joint under a pressure of 100 lbs. per square inch may be anticipated.

W. A. McFarland, Supt. Washington, D. C. 2600 underground leaks in water mains found by him prior to October 28th, 1911:

		Daily
1373	service pipe leaks	13,669,000 Gals.
607	main joint leaks	8,076,000 Gals.
620	miscellaneous leaks	5,520,000 Gals.
2600	Leaks	27,265,000 Gals.

Commissioner Henry S. Thompson, New York City, placed water wasted by leaks in the streets from distribution on mains third in the list of principal water wastes.

T. C. Phillips, testing Chicago water mains found in 25.8 miles of streets 5,243,000 gallons per day flowing away from defective joints, services, etc. One 12″ main leaked 1,638,000 gal. per day; nearly one-half this quantity in one block.

The leakage at the joints of a steel line is practically nil, whereas, in a cast-iron line employing lead joints, each connection forms a slip joint, which sooner or later may become leaky. Statistics covering twenty-two year's operation of a twenty-four inch line at Rochester, N. Y., show that of the 307 leaks developed during that period 297 were leaks at the lead joints, each one of which had to be repaired. A steel line has a riveted, caulked joint which once made tight remains so. A cast-iron line has many more joints and consequently more opportunities to leak than a steel line made up in thirty foot lengths.

Three miles of the above mentioned line at Rochester is W. I. pipe. During 40 years of continuous service, but two leaks have been discovered through the plate and both of these were on the same sheet.

During the same period 10 leaks were discovered through as many sheets of the 36″ W. I. Rochester Conduit I which was $\frac{3}{16}$″ thick and 9.6 miles long.

CAST IRON PIPE FAILURE

Boston, Mass.

This cast iron pipe line was laid in 1896 and was known as Class A Pipe

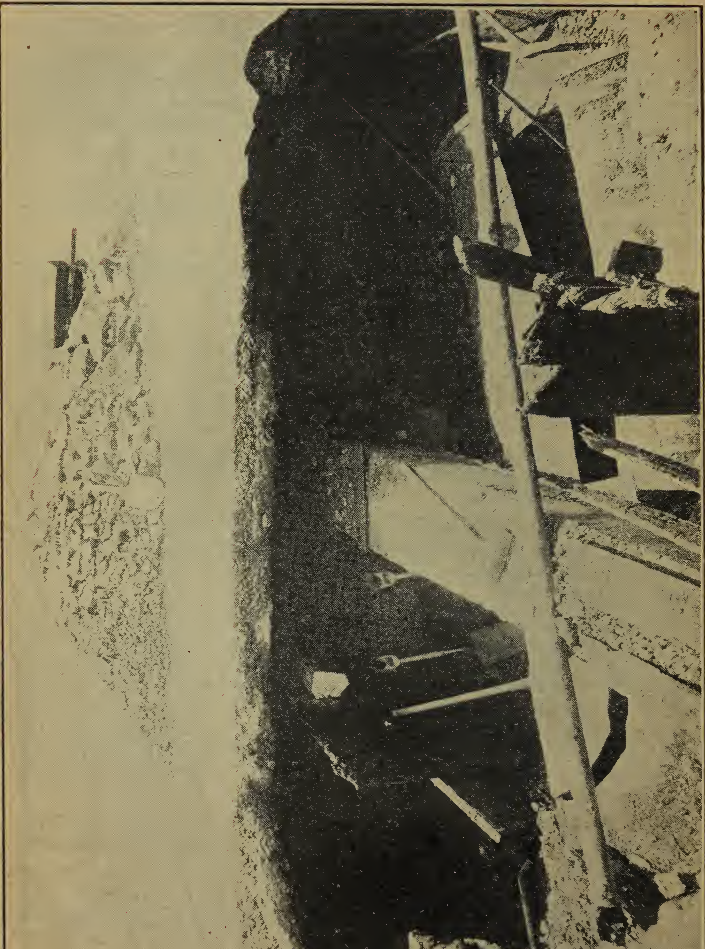


Fig. 50—Failure of a 42" Diameter Cast Iron Pipe. City of Boston, Mass. Note the manner in which the Pipe cracked.

1-16/100 inches thickness of shell. It was under a pressure of from 90 to 95 lbs. and was 42 inches in diameter. The length that failed, as may be seen from the illustration, cracked on the top side, the crack extending from the bell end to within one foot of the spigot end, where it turned at right angles and followed the circumference of the pipe about three-fourths of the way around.

The following story of the resulting damages, as condensed from the Boston Globe, June 21, 1916 is the usual familiar one accompanying a severe break. When a cast-iron pipe fails it goes all at once and the resulting damage is therefore severe. Steel Pipe on the other hand, does not subject life and property to danger; the worst that may happen is a small leak, quickly and easily repaired.

In the excitement and bustle of a mobilization of the Militia, and at the end of a season of rain, which has not been equalled in local weather history, the bursting of a 42-inch water main in Copley sq. early this morning, cutting off the water supply for the entire downtown business section of the city, was considered by those who witnessed and suffered from it, as only a trifle because the thousands of gallons of water which was wasted can easily be spared, although it made a real island of that section of the city and did considerable damage by filling cellars.

Copley Sq. Green was completely surrounded by swift running waters two feet deep from 6 to 8 a.m. It flowed in a torrent down Blagden St. by the south end of the magnificent Public Library Building, through Dartmouth St. in front of and along Boylston St. beside it. The flood raced from the railroad bridge on Dartmouth St. across to Newbury St., then along Huntington Av. from the incline in front of Hotel Nottingham Building back almost to Berkeley St., through Clarendon St. from Boylston St. to the railroad and along Boylston St. from Clarendon to Exeter St.

The greatest water damage discovered early this morning was apparently done to the basement of the Hotel Westminster, into which ran 500 or 600 gallons that drenched the Winter garden, the engine and boiler rooms and other basement rooms.

The cellar of the S. S. Pierce Building at the corner of Dartmouth St and Huntington Av. was also flooded, and considerable loss in the perishable stock resulted.

The Public Library cellar also was invaded by the swift-running water and the engineer was obliged to haul his fires as a precautionary measure.

The Copley-Plaza Hotel was completely isolated as if it were on an island, no appreciable damage was done there because the corps of porters succeeded in keeping the water out of the cellar by fighting it back at the curbing with brooms.

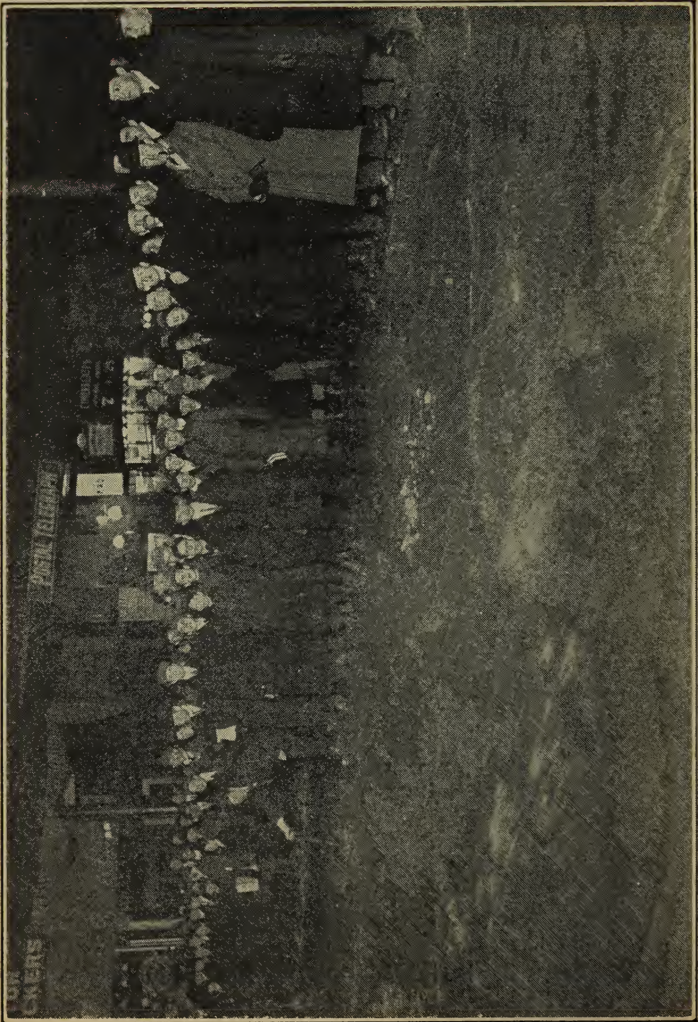


Fig. 51—WHAT HAPPENS TO THE STREET WHEN A CAST IRON WATER MAIN FAILS.

The cellar of the old Nottingham Hotel, which is being remodeled, was filled with water, but no great damage appeared to have been done for there was nothing there to be damaged.

At 5:50 A. M. the water burst forth in a column a dozen feet in diameter, and rising nearly 15 feet in the air, with tons of earth and stones upon its crest. The column of water was accompanied by a powerful odor of escaping illuminating gas, which caused some to fear that a gas main also was broken.

The police notified owners of large buildings downtown to draw the fires under their boilers as the water supply would be cut off for hours and this step had to be taken to prevent boiler explosions.

The exact location of the break in the water main was on Dartmouth St. a few feet from the front southerly corner of the Public Library Building, on a direct line to the corner of the Copley-Plaza Hotel, which is made by the junction of Dartmouth St. and Huntington Av.

Within five minutes the guests of the Copley-Plaza and the Hotel Westminster were up and dressed and gazing from all the windows at the flood and some anxiously asked the hotel clerks if it would be necessary for them to vacate in haste. All early rising guests at once discovered something was wrong for the water supply in the hotels had been automatically cut off.

Firemen and watchmen in many large buildings in the city instantly noticed that the water supply had vanished and all made instant inquiries, and then took necessary precautions. Some banked and others drew their fires or utilized auxiliary supplies provided for just such emergencies.

In racing along Blagden St. the torrent filled the catch basins, which backed up all over the neighborhood and also began bubbling small founts, which contributed some debris to the flood.

A street car which came in town along Huntington Av. became wedged in the mud and stones which covered the tracks. Another car which came along later was hooked on to the stalled one and hauled it to a place of safety. All cars routed for the vicinity of the flooded territory were diverted through other streets so as to avoid the flood.

Two automobiles were stalled in the water which came up to their bodies and short circuited their magnetos and put them out of commission. Other autos were run into the water and lines were made fast to those that were crippled and they were hauled out by emergency cars, which kept a safe distance from the deep water.

During the flood the streets were spotted with refuse barrels, large waste paper metal boxes, hokey pokey wagons and the like which had been swept from their stands by the swift running water and carried on the crest of the torrent hundreds of feet distant.

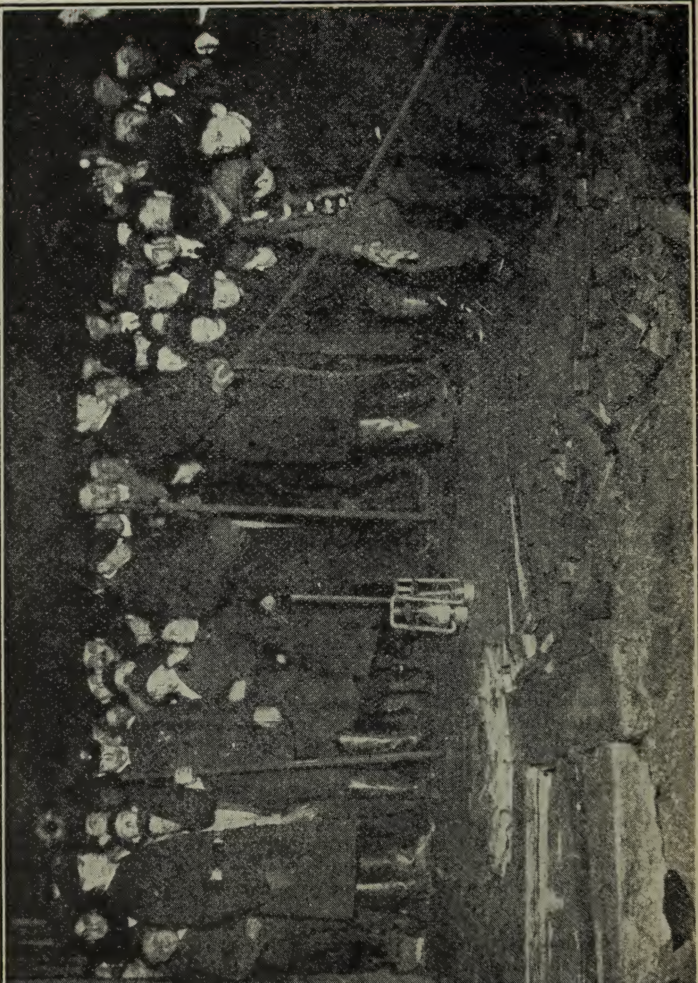


Fig. 52—WHAT A CAST IRON PIPE FAILURE DOES TO THE PAVEMENT

The macadam street was distorted by the waters which had raced under it and the surface was lifted and carried out of place to the curbings and left high over the sidewalks in front of the Library Buildings.

The water was so deep and ran so swiftly that horses refused to try to ford it.

All street car service in the vicinity was cut off two and a half hours and the Elevated Railway operated a jitney line between Copley sq. and Massachusetts Av.

Burst In Largest Main

The main which burst is the largest in the city. It is a 42-inch pipe, which extends from the Fisher Hill reservoir in Brookline through Huntington Av. to Boston Common, where its supply is diverted into the smaller mains that reach out in all directions, carrying the supply to the entire city.

It was hours before those in the residential districts as far away as Dorchester and Roxbury could understand why water would not flow from their faucets and the plumbers were rushed to death with hurry calls from alarmed householders.

"The pipe was laid in 1896 and is the main supply for the high-service district in the city proper, the district being bounded approximately by Charles and Kneeland Sts., Atlantic Av., Clinton, Blackstone, Merrimac, Chardon and Cambridge Sts. This main connects directly to Fisher Hill Reservoir and there is a normal pressure of from 90 to 95 pounds. A section of pipe 10 feet in length and practically one-half of its diameter was found blown out or pushed away about 1½ feet from the remainder of the pipe and the bell end of the section broken.

"The records of the Venturi meters on the high service system show that there was an increased consumption between 5.40 a.m. and 7.20 a.m. at the rate of 40,000,000 gallons per 24 hours over the normal rate at this time of day, so that the water was wasting through this defect at the rate of 1,670,000 gallons per hour."

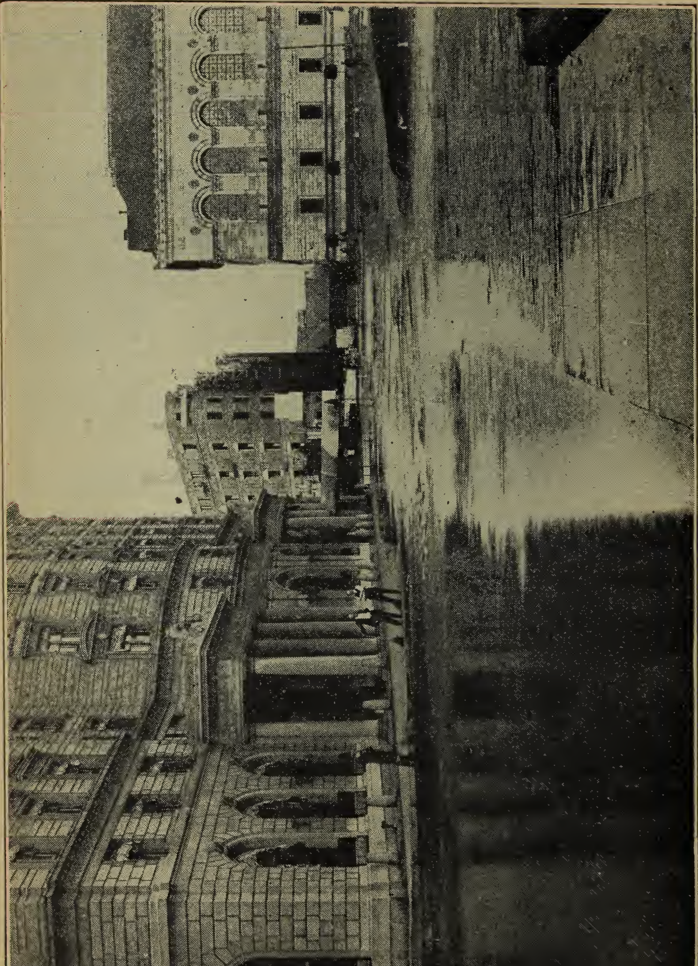


Fig. 53—A CAST IRON PIPE FAILURE, TURNS BEAUTIFUL STREETS INTO RIVERS AND CELLARS INTO PONDS.

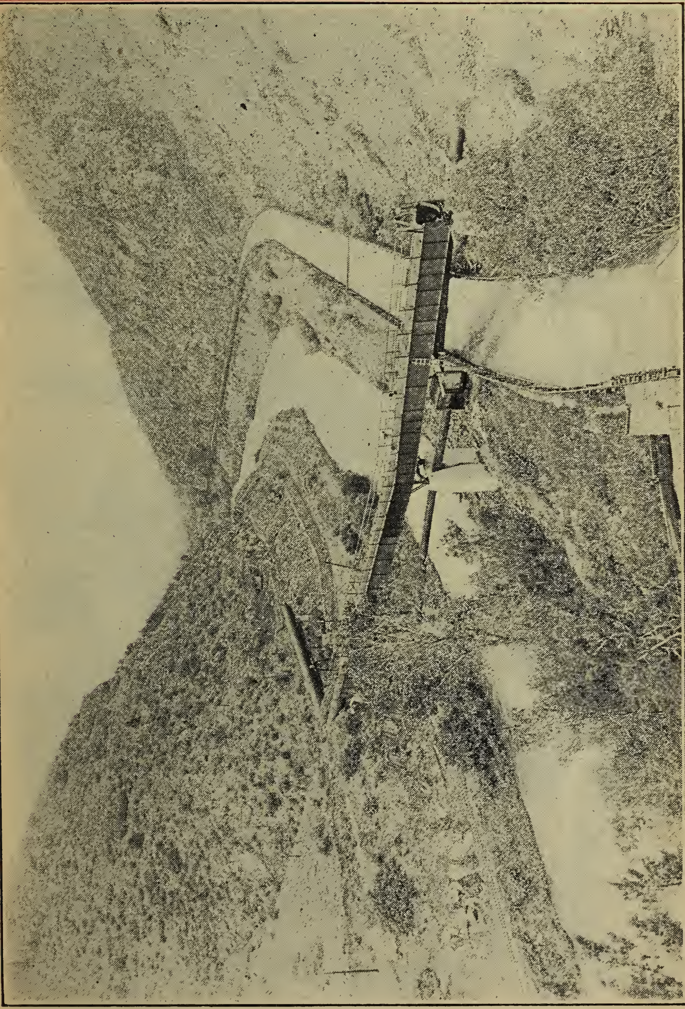


Fig. 54—"LOCK-BAR" Steel Pipe on bridge over South Platte River. Denver Union Water Company.

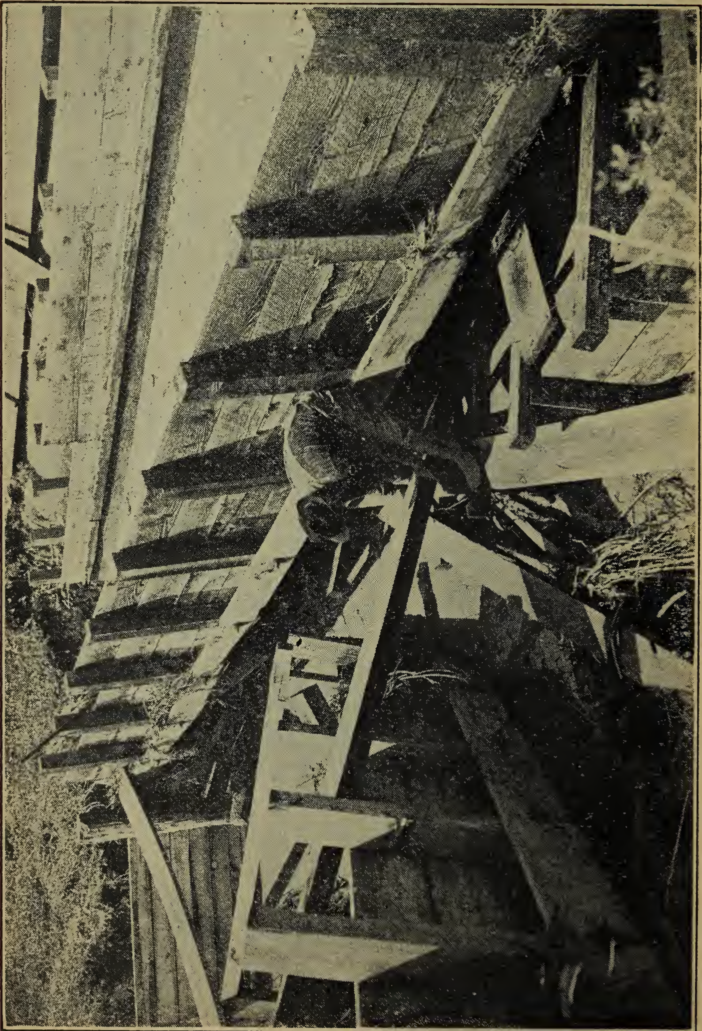


Fig. 55—Denver Union Water Co.—City Ditch flume and other wreckage carried by flood and lodged against "Lock-Bar" Steel Pipe.

THE DENVER UNION WATER COMPANY

DENVER, COLORADO

August 23, 1912

The East Jersey Pipe Company,
50 Church St., New York, N. Y.

Gentlemen:-

In reply to your letter of August 20th, we beg to state that none of our steel pipe burst during the flood referred to in the newspaper clipping. We had several breaks in cast iron pipes crossing Cherry Creek, which stream was the one in flood at that period.

The Lock-Bar Steel Pipe crossing Dry Creek, which was also in flood at about that time, was subjected to a very severe test, and I am enclosing you herewith photograph showing the wreckage lodged against the Lock-Bar pipe which we purchased from you a few years ago, which pipe is located in the conduit, designated by our Company as Conduit No. 6.

We are also enclosing you photographs showing the construction of the 60″ Lock-Bar pipe, crossing the South Platte River, which will explain themselves.

Yours very truly,
(Sgd.) D. G. Thomas,
Chief Engineer.

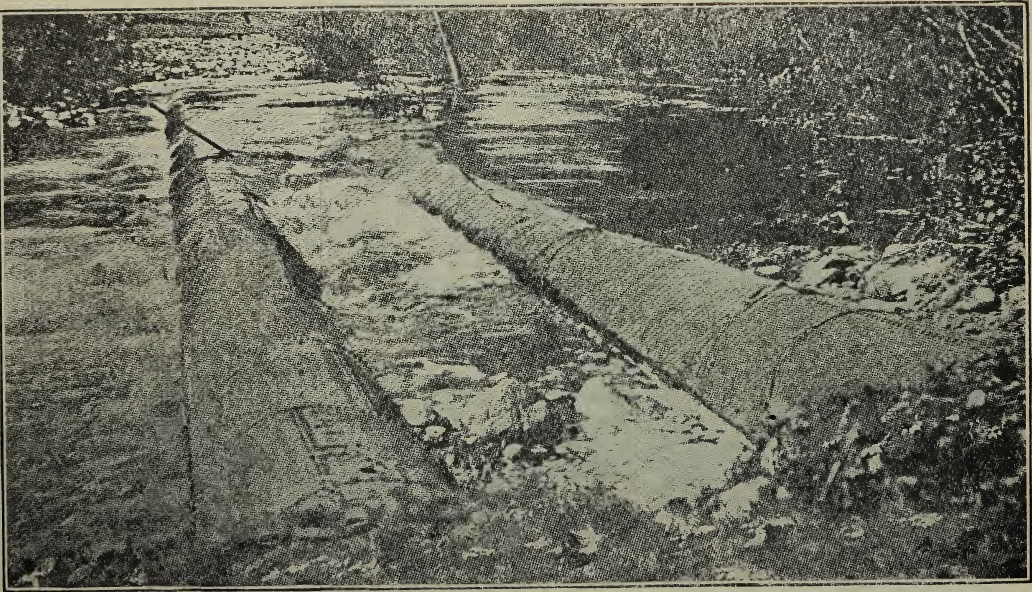


Fig. 56—48-INCH RIVETED STEEL CONDUITS, CITY OF NEWARK, N. J.

Shows the same conduits near Macopin Intake, where the Pequannock River was diverted when pipes were laid, and the pipes were placed in the old river bed. The flood broke the bank of the new course, and the water washed all the earth from the pipes, which withstood the force of the torrent, although exposed for over 50 feet.

EXTRACT FROM THE MINUTES OF THE BOARD OF STREET AND WATER COMMISSIONERS OF THE CITY OF NEWARK, N. J., AT ITS MEETING, OCTOBER 13TH, 1903.

Engineer M. R. Sherrerd, of the Water Department, reported regarding the extent of the damages caused by the flood at the Pequannock watershed and along the Newark Pipe Lines in the Passaic Valley. The most threatening danger to the pipe lines occurred about a mile and a half below the Macopin Intake, where the two lines of 48-inch riveted steel pipe were left suspended in the air for a distance of about 35 feet, caused by the washing out of the lower portion of one of the abutments to a culvert under the pipe lines. The waterway of this culvert, about 10 x 14 feet, ordinarily sufficient to take the flood flow of a small mountain stream passing under the pipes at this point, became blocked with trees which were uprooted by the torrent caused by the breaking of a dam on a small pond on this stream. Not only were these trees, some thirty in number, washed down the steep side hill and piled on the pipes, but the masonry of the upper portion of the abutment was also resting across the two pipes where the washout occurred. One line showed a slight weeping, while the other, apparently, was not in any way affected. Both lines at the time were carrying, approximately, their full capacity, and the weight of the water in the pipes, without the superimposed load, would have been sufficient to have broken cast-iron pipe.

The engineer stated that the results of the flood showed conclusively the necessity of the new storage reservoir, with its ample capacity of 700 million gallons and its seven miles of independent 60-inch steel pipe line, which are now being constructed, *as well as the advantages of the use of steel pipe lines for these long conduits over cast-iron, as the latter would not have withstood the washouts in the manner the steel pipes proved able to do.*

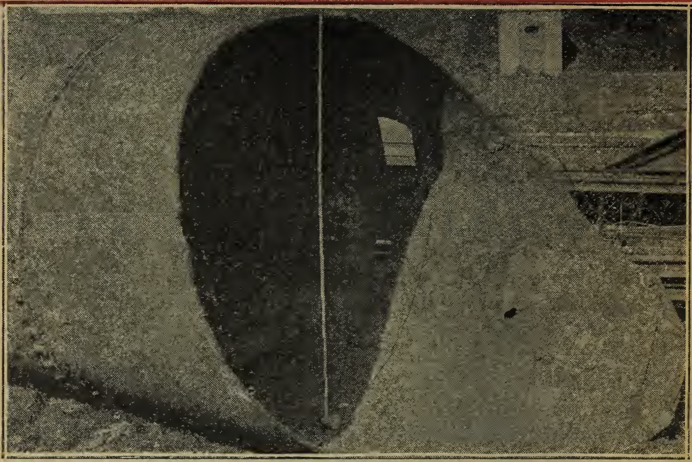


Fig. 57

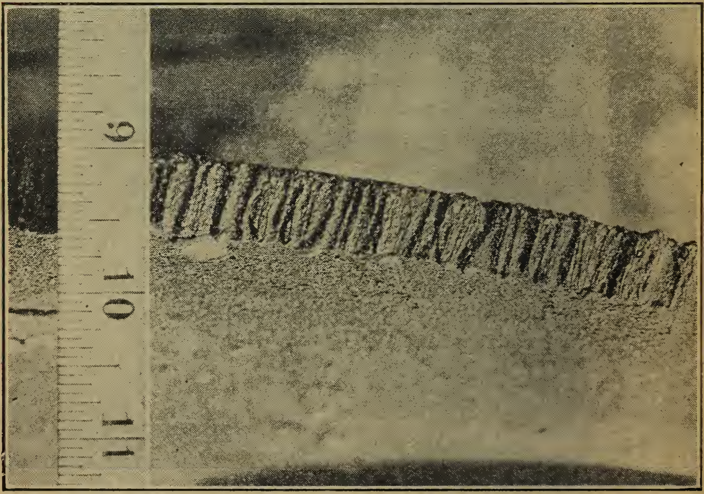


Fig. 58

Photographs taken in 1918 of test cuts made to determine the condition of a 10 mile, 60 in, riveted steel pipe line laid for the city of Allegheny, (now part of Pittsburgh, Pa.) in 1895 by T. A. Gillespie Co. The letters reproduced on the two following pages tell their own stories.

AN EXPERIENCE IN CANADA

In the February 26, 1914 issue of The Canadian Engineer, published at Toronto, Ont., Can. appears a description of the reclamation of a 40″ steel pipe line laid over a quarter of a century previous to that date in the Ottawa River.

From this article the following significant paragraphs are reprinted.

"The pipe was then disconnected and each length of about 45 ft. was tested. The old cast-iron flanges were then cut off and the rivets and seams caulked where necessary."

"After this had been done the pipes were placed in the desired alignment and riveted together by means of steel sleeves, so as to form one continuous pipe from the pump-house ——— giving an approximate length of 200 ft."

"Then curved flanges were riveted on each end and the pipes tested to a pressure equal to twice the working head."

"In the old pipe, cast-iron ball joints were used, but, *not being found satisfactory,* have been discarded altogether, and special angle pieces are being used instead."

"Considering the length of time these pipes were in the river, their condition was marked in that there was practically no corrosion."

CITY OF PITTSBURGH

PENNSYLVANIA

DEPARTMENT OF PUBLIC WORKS
JOHN SWAN
DIRECTOR

March 26th, 1919.

T. A. Gillespie Company,
Pittsburgh, Penna.

Gentlemen:

Relative to your inquiry as to our experience with steel pipe, beg to inform you that the former City of Allegheny, now a part of the City of Pittsburgh, laid a 60 inch steel line from the City to Montrose Pumping Station, a distance of about ten miles in 1895. In 1918, we had occasion to lift about 40 ft. of this line to put in some gates and connections. We found that upon moving two sections of this 60 inch line, it was practically in perfect condition. Tests which were made for corrosion and weight showed that the steel had lost comparatively nothing in this length of time. From all appearances, I would judge that this line was good for at least 25 years more.

Yours very truly,

John Swan

Director.

CITY OF PITTSBURGH

PENNSYLVANIA

DEPARTMENT OF PUBLIC WORKS
BUREAU OF WATER

CHAS. A. FINLEY, MANAGING ENGINEER

File 1801 - 2.

March 26, 1919

The T. A. Gillespie Co.,
Pittsburgh, Penna.

Gentlemen:

In March 1914, the City had occasion to make three (3) 24" pressure connections with the 60" steel pipe line which was laid about 1895, from Montrose Pumping Station to the old Troy Hill Reservoir, a distance of about ten miles. Three (3) 24" cuts were made in the side of the steel pipe and the condition of the pipe carefully noted. The original thickness of the plate is recorded as one-half inch. The cuts, upon careful measurement, still show the full original thickness. We were unable to demonstrate any appreciable deterioration in the pipe during the twenty-years that it was in service.

In 1918, it again became necessary to cut the same line at the Filtration Plant, this work being done with an acetylene torch. The pipe was found to be in good condition and showed no appreciable loss of metal due to the twenty four years of service. The condition in which this pipe was found, would indicate that it was entitled to credit for much longer service than it has been customary to grant to this type of steel.

About the time this pipe was laid, if I remember correctly, it was very strongly contended that this pipe would only be good for about thirty years. It has now been in service twenty-four years and the condition of the pipe indicates that its possible life was under-estimated.

I am enclosing photographs.

Yours very tr

Chas. A. Finley.

Managing Engineer

CAF/WTD

EE

FORM 196 E.

JOHN F. GALVIN
CHARLES N. CHADWICK
L. J. O'REILLY
COMMISSIONERS
J. WALDO SMITH
CHIEF ENGINEER
THADDEUS MERRIMAN
DEPUTY CHIEF ENGINEER

BOARD OF WATER SUPPLY
CITY OF NEW YORK
ENGINEERING BUREAU
MUNICIPAL BUILDING

NEW YORK, February 24, 1920

Subject: Lock-bar pipe

Mr. H. Seaver Jones,
Vice President, East Jersey Pipe Company,
50 Church Street, New York.

Dear Sir:

In response to your inquiry regarding the superiority of lock-bar pipe, I beg to submit the following.

In this vicinity there is a strong preference for lock-bar pipe for all sizes to which it is adaptable. The East Jersey Water Company, the largest user of steel pipe in the East and which has laid several hundred miles, has not, since the perfection of the lock bar, used any other type. Its particular advantages are:

1. Additional strength for the same thickness of pipe.
2. Superior hydraulic qualities, due to the elimination of 75% of the circular riveted joints and one riveted longitudinal seam and the ability to produce a smoother coating.

The amount of gain in carrying capacity is largely a matter of judgment, for so far as I know, there have been no reliable experiments of capacity of riveted and lock-bar pipe of the same age under comparable conditions.

That the gain in capacity is considerable is unquestionable. My own judgment is that it might easily reach 15%, as the smoothness of coating in itself conduces to a higher coefficient. The little roughnesses in riveted pipe, such as are caused in the dipping and draining of the pipe by the presence of the rivets, to which the coating is apt to adhere and drip during the draining process, together with the rivets and seams, increase the friction more than is supposed.

The lock-bar pipe was used on the Catskill work wherever it was applicable, such as some of the main delivery lines within the city. In the light of present experience, one would hardly consider the use of riveted pipe if lock bar could be secured

As to the life of steel pipe, in broad terms a pipe protected with the best type of coating and well laid should last upwards of 50 years. This estimate is based on knowledge of lines built in the East, where the coating was inferior to that now available and which have been in operation over 20 years and seem to be good for an indefinite period. Also lines in California have been in operation around 40 years and where examination has been made show only a slight deterioration. The engineers of the Board of Water Supply had confidence enough in steel pipe to lay it in the streets, believing that it would compare very favorably in its life with cast-iron pipe.

Very truly yours,
J. Waldo Smith
Chief Engineer

N. W. Tel. Main 3402

F. W. Cappelen

M. Am. Soc. C. E., M. Am. Soc. M. E.
M. Am. Water Works Assn.

Consulting Engineer.

610-611 Globe Bldg., Minneapolis, Minn. Dec. 29, 1911

TO WHOM IT MAY CONCERN:

I beg to herewith submit my experience with riveted steel pipe.

As City Engineer of Minneapolis I had occasion in 1897 to build two large pipe lines for the City.

After a thorough investigation I was convinced that steel pipe would in every was satisfy the existing conditions, but to please the advocates of cast-iron, bids were received for both steel and cast-iron pipes. The steel was fifty inches in diameter, the cast iron pipe forty-eight inches; Maximum pressure 125 pounds per square inch; Total length of pipe 33,000 feet, of which 1,500 feet were submerged, crossing the Mississippi River.

Lowest cast-iron bid	$477,500.00
Lowest steel pipe bid	343,726.00

On June 18,1897, contract for steel pipe was awarded to the T.A.Gillespie Company of Pittsburgh and the entire Job finished November 9th of the same year - a most remarkable record - and I cannot too highly recommend the T. A. Gillespie Company for doing splendid work in every respect.

I have several times had occasion to examine this pipe line personally, both inside and outside, and found the coating just as good as new.

The coating used was the so-called Rubber Asphaltum, manufactured by the Assyrian Asphalt Company of Chicago, now the American Asphaltum & Rubber Company of Chicago. I determined the use of this particular coating after exhaustive tests and experiments.

We have never had a leak on the entire line since the water was turned on, fourteen years ago. We have on the other hand a constant trouble with submerged cast iron line of which we have three across the Mississippi.

I have also been connected with the 6 to 8 miles long 42 inch steel pipe lines for Seattle, Washington Water Works, with entirely satisfactory results. I have also put in steel intakes on very exposed places on Lake Superior. The steel mains stood the racket, but the cast iron specials in connection with the work did not.

Taking the saving and everything else into consideration, I recommend large steel pipe instead of cast iron pipe. Of course with the proviso that the steel pipe is properly designed, manufactured and laid.

Respectfully,

FWCappelen

WATER DEPARTMENT
Office of the Chief Engineer
WILMINGTON, DEL.

April 8, 1907

Mr. T. A. Gillespie,
New York, N. Y.

Dear Sir:

When the duty devolved upon us to decide on the class of pipe to be used for the mains for the extension of the water supply system of this city, the first question was as to the relative merits of steel and cast-iron, and this was decided purely on economic grounds, the saving to the city by the adoption of steel pipe being approximately $40,000 or 25% of the cost of cast-iron pipe.

The second question was to decide between the ordinary riveted and the lock-bar pipe. At that time the lock bar pipe was an innovation in this country, and there being no precedent to follow, it was necessary to arrive at a conclusion based solely on our own judgment of the mechanical merits of the lock-bar as a serviceable joint, as compared with the usual longitudinal riveted joint, having in mind the unbroken interior surface presented by the lock-bar pipe, with the consequent reduction in friction, and for your satisfaction I am presenting herein the reasons which actuated the final decision to adopt lock-bar pipe, apart from any slight difference in cost between it and riveted pipe.

It is an established fact that a riveted joint, such as is usually presented in the all-riveted pipe, under most favorable conditions will not develop over eighty per cent of the tensile strength of the plate, and in consequence of this it becomes necessary to use a plate 25 per cent thicker than would otherwise be required to overcome the weakness of the joint. A satisfactory series of tests having established the fact that the lock-bar pipe, when properly proportioned, will produce a joint as strong as the plate itself, it becomes apparent that by utilizing this style of joint, one of two results is obtained: either a plate 25 per cent thinner than for riveted pipe may be used, or if the same thickness of metal is retained, 25 per cent greater strength is obtained. Whichever way it may be taken, there is a gain in this point of 25 per cent in favor of the lock-bar joint. Assuming that in the average pipe the metal represents one half of the final cost of the pipe, the economic advantages would, therefore, be 12½ per cent in favor of the lock-bar pipe.

Regarding the relative carrying capacity of the lock-bar pipe with its continuously regular inside surface, and the ordinary riveted pipe with inner and outer sheet forming a break in the continuity of the surface every seven feet, it becomes self evident that the frictional resistance of the latter will be largely in excess, and inversely the velocity and carrying capacity of the lock-bar pipe proportionately greater. There is no data extant at this time to demonstrate conclusively the actual difference in velocity of flow between these two forms of pipe, but in an endeavor to reach a fair conception of this difference, it has been assumed that a variation of .001 in the co-efficient of the Kutter formula would probably result in as close an approximation as circumstances would warrant. Based on this assumption, the capacity of the lock-bar pipe, 48 inches in diameter, would be 8½ per cent greater than a riveted pipe of the same diameter. Other sizes would vary proportionately.

As a resume, therefore, it may be stated that the lock-bar pipe possesses two points of marked supremacy over riveted pipe, first, an advantage of 12½ per cent in the value of the pipe due to its increased strength, and second, 8½ per cent on account of greater capacity, a total of 21 per cent to the credit of the lock-bar pipe.

These deductions may be open to some alterations due to conditions; cost of manufacture; size of pipe, and some other minor points, although in general they may be accepted as fair. But making due allowance for some such criticism it may be stated broadly that the net value of the lock-bar pipe is from 15 to 20 per cent greater than riveted pipe of the same diameter and thickness.

Respectfully,
(Signed) THEODORE A. LEISEN

BUREAU OF WATER
PHILADELPHIA, PA.

August, 7, 1908

East Jersey Pipe Company,
New York City.

Dear Sirs:

Complying with your request for an expression of my opinion of the strength, carrying capacity and durability of Lock-Bar Steel Pipe compared with riveted steel pipe, I would say that the City of Philadelphia has completed the installation of some 54,000 feet of 48-inch and 36 inch Lock-Bar Steel Pipe, which was laid under most adverse circumstances, and I believe this pipe to be from twenty to thirty per cent stronger than double riveted pipe made of the same thickness of plate, because double riveted joints, such as are generally used in the manufacture of riveted steel pipe, have from twenty to thirty per cent less tensile strength than the plates thus joined, while tests have shown Lock-Bar joints, when properly made, to have strength equal to the plates themselves.

The carrying capacity of Lock-Bar Steel Pipe is probably ten to twelve per cent greater than that of the ordinary in and out or taper sheet, riveted pipe. As far as I know there have been no tests made to determine this point, but in my opinion, the continuously regular inside surface of the Lock-Bar Pipe, with circular joints thirty feet apart, will produce no greater frictional resistance than well coated cast iron pipe with joints every twelve feet.

The natural life of Lock-Bar Steel Pipe is undoubtedly greater than that of ordinary riveted steel pipe similarly coated because it is made with smooth, continuous inside surface, with circular joints at thirty feet intervals only and few projecting rivets, while riveted steel pipe has circular joints at least every seven and one-half feet and many projecting rivets, and at each the coating, which prolongs the life of steel, is more easily torn or worn off, thus exposing the bare metal to corrosive action, and further on account of the fewer number of joints and fewer rivets the leakage of the Lock-Bar Steel Pipe is less than that of the ordinary riveted steel pipe.

Yours very truly,
(Signed) F. C. DUNLAP,
Chief of Bureau.

KANSAS NATURAL GAS COMPANY

FARMERS BANK BUILDING

Pittsburgh, Pa.

December 19, 1911

T. A. Gillespie, President,
The T. A. Gillespie Company,
71 Broadway, New York.

Dear Sir:

In the year 1901, while general manager of the Philadelphia Company of this city, I lifted some twelve miles of 36 inch riveted steel pipe laid by you for that company about the year 1886-1887, from the Murraysville Field to Pittsburg. I found this pipe in perfect condition; in fact, the mill bloom was scarcely off the iron in many places, and not a joint of it was lost or a patch used in relaying. None of the lateral seams required caulking. This line had expansion joints (a device of your own) about every 175 feet, that is the most perfect working expansion joint that I ever had any experience with. The line has been in successful operation under a pressure of from 65 lbs. to 100 lbs., has never given any trouble, and is a perfect line today, seemingly as perfect as when first laid.

I have knowledge of other steel lines of smaller size that have been in good service from fifteen to twenty years, and are apparently in as good condition today as when first laid.

Yours very truly,
(Signed) J. C. McDOWELL

File No.

MORRIS R. SHERRERD,
Chief Engineer

JAMES C. HALLOCK,
Deputy Chief Engineer

Department of Public Works

BOARD OF STREET AND WATER COMMISSIONERS,
NEWARK, N. J.

CITY HALL. Dec. 26th, 1911

T. A. Gillespie Company
50 Church Street,
New York City, N. Y.

Gentlemen:

Replying to your inquiry in regard to the condition of the steel pipe lines which your company laid in connection with the new water supply for the City of Newark, I would advise you that the first line, laid in 1891, consisting of 21 miles of 48 inch and 5 miles of 36 inch rivetted steel pipe, and the second line, laid in 1896, consisting of 5 miles of 48 inch and 16 miles of 42 inch rivetted steel pipe, and the third line, laid in 1904, 7 miles of 60 inch rivetted steel pipe, have all given very satisfactory service, and have been in continuous use since laid. The only serious difficulty we have had with any of the lines was at one spot, where for a distance of about 1200 feet, two lines of pipe were laid through a peat swamp, the soil of which was of a peculiar nature and was back-filled directly against the pipe. Electrolytic action has taken place at this point either from stray currents from the trolleys, or from local action in the soil. We were able to repair without difficulty slight leaks in this section, and have filled around the pipes with gravel. The trouble happened over a year ago, but we have not been bothered since. The nature of the swamp was such that it would seem very probable cast-iron pipe would also be affected in a serious manner.

You will remember that in asking for bids for the 60 inch pipe line referred to above, we also asked for bids for cast iron pipe, and found that the difference in cost was so great that we could have renewed the steel pipe in 13 or 14 years for the difference, and that our decision was at that time favorable to steel pipe.

Considering the difference in first cost, I am satisfied that it has been of advantage to us to lay steel pipe, and that it would generally be advantageous to use this class of material for supply pipe lines when the same are well constructed and given a tenacious asphalt covering.

Very truly yours,

M. R. Sherrerd

Chief Engineer

Montreal Water & Power Co.

Montreal, Feb. 5, 1912

The East Jersey Pipe Co.,
50 Church Street,
New York City, N. Y.

Dear Sirs:-

Replying to your letter asking for information as to the carrying capacity of lock bar pipe, we beg to hand you the following.

We have a line approximately 36,000 feet in length and are pumping into this at the rate of 11,800 U. S. gallons per minute by Venturi Meter. At a point 12,000 feet from the pump station water is drawn at the rate of 2,333 U. S. gallons per minute, also measured by Venturi Meter. Readings of pressure were taken with Bristol recording pressure gauges, and the gauges tested by means of a Crosby gauge tester before and after the 12 hours records. Elevations of gauges were well established. The average friction loss for three hours while conditions were constant in the whole line was 28.27 feet. The figure given in Coffins tables for clean cast-iron pipes under the above conditions is 30.7 feet, and, in our experience the actual friction loss in cast-iron pipes that has been in service a few years is about 50% higher than is given in these tables. Hence we estimate that if this line were laid in cat-iron, the friction would be at least 45 feet or 59.2% more than the observed friction in our steel main. The first section of this main, 12,000 feet, was laid in 1907 and 1908 and the balance in 1909.

Yours truly,

MONTREAL WATER & POWER COMPANY

W. H. Sutherland

Asst. Eng.

Dict. WHS

PREFERENCES ACCORDED LOCK-BAR PIPE IN COMPETITION WITH OTHER TYPES.

The high longitudinal joint efficiency of Lock-Bar Pipe permits the safe utilization of a given thickness of plate against a higher working pressure than would be possible for the same plate thickness if incorporated in a pipe of lower joint efficiency. This fact is usually considered by Engineers and is instrumental in effecting considerable saving in plate tonnage, particularly in long supply lines where a gradual but consistent increase of pressure is encountered.

The carrying capacity of Lock-Bar Pipe, owing to the smooth interior unobstructed by rivets, is from 10% to 15% greater than that of riveted pipe. This means that in order to carry a given volume of water under similar conditions a riveted pipe must be of greater diameter than a Lock-Bar Pipe.

By reason of these features Lock-Bar Pipe is usually given preference for strength when in competition with welded pipe and for both strength and carrying capacity when in competition with riveted pipe. In some instances this is stipulated as a 10% money preference in price on pipe laid. In others the specifications provide that riveted pipe shall be of larger diameter and of greater plate thickness than Lock-Bar Pipe.

Some Steel Pipe Lines Manufactured by the East Jersey Pipe Company

Year	Location	Kind	Size in.	Length ft.
1891	Newark, N. J.	Riveted	48 and 36	142,000
1896	Newark, N. J.	"	48 and 42	126,000
1897	Paterson, N. J.	"	42	40,000
1899	Seattle, Wash	"	42	32,000
1899	Newark, N. J.	"	51	47,500
1900	Utica, N. Y.	"	96	1,000
1902	Jersey City, N. J	"	72	93,000
1903	Newark, N. J.	"	60	39,300
1903	Troy, N. Y.	"	33	35,300
1903	Schenectady, N. Y	"	36	24,000
1904	Astoria, Long Island	"	60	15,000
1905	Pittsburgh, Pa.	Lock-Bar	30	2,500
1905	Paterson , N. J	"	48 and 42	11,000
1905	Lynchburg, Va.	"	30	15,000
1905	Wilmington, Del.	"	48 and 43	20,000
1906	Brooklyn, N. Y.	Riveted	72	42,300
1906	Honolulu, T. H.	Lock-Bar	30	8,000
1906	Philadelphia, Pa	"	48 and 36	55,300
1907	Gary, Ind.	"	36	4,000
1907	Trenton, N. J	"	48	10,000
1907	Montreal, P. Q.	"	36	11,000
1907	Lockport, N. Y.	"	30	68,500
1907	Vancouver, B. C.	"	22	5,000
1908	Michigan City, Ind	"	30	4,000
1908	Philadelphia, Pa	Riveted	132	3,180
1908	Montreal, P. Q.	Lock-Bar	36	25,000
1908	Springfield, Mass	"	54 and 42	63,500
1909	Brooklyn, N. Y.	"	72	83,000
1909	Portland, Ore	"	48 to 24	9,600
1910	Brooklyn, N. Y.	"	48	16,200
1910	Ensley, Ala	"	50	8,840
1910	Pittsburgh, Pa.	"	24	5,000
1910	Cuba	"	36 and 28	1,300
1910	Washington, D. C.	"	30	1,220
1910	Seattle, Wash	"	32	4,050
1910	Seattle, Wash	Lock-Bar	42 to 24	12,300
1910	Portland, Ore.	"	52 and 44	128,000
1910	Butte, Mont	"	42	1,200
1910	New York City, N. Y.	"	48 to 30	1,200
1910	Catskill Aqueduct, N. Y	Riveted	135, 117 and 114	33,000
1911	Catskill Aqueduct, N. Y	Lock-Bar and Riv.	66	17,020
1911	Lakeland, Fla	Lock-Bar	20	4,020
1911	Pennsylvania R. R	"	20	7,770
1911	Massena, N. Y.	"	24	1,320
1911	Seattle, Wash	"	42, 40, 36 and 24	16,945
1911	Montreal, P. Q.	"	48, 36 and 30	7,300
1911	Denver, Colo.	Lock-Bar	60	1,200
1911	Marquette, Mich	"	66	8,000
1912	Chihuahua, Mexico	Riveted	102	1,400
1912	Union Bay, B. C.	Lock-Bar	50	1,320
1912	Rochester, N. Y	"	66	9,254
1912	Ottawa, Ont.	"	42	2,400
1912	Omaha, Neb	"	48	10,550
1912	Akron, Ohio.	"	36	55,870
1912	Winnipeg, Man.	"	36	42,500
1913	Minneapolis, Minn.	"	54, 50 and 48	39,725

Year	Location	Kind	Size in.	Length ft.
1913	Montclair, N. J	Lock-Bar	24	7,295
1913	Massena, N. Y	"	24	1,200
1913	Utica, N. Y	"	36	1,000
1913	Wilkesbarre, Pa	"	36	1,335
1913	Schenectady, N. Y	"	24	2,420
1913	Kansas City, Mo	Riveted	48	1,220
1913	Croghan, N. Y	"	114	2,555
1914	Schenectady, N. Y	Lock-Bar	36	10,500
1914	Essex Junction, Vt	Lock-Bar and Riv.	108 and 36	2,440
1914	Rutland, Vt	" " "	54	2,750
1914	Winnipeg, Man	Lock-Bar	36	24,000
1914	Brooklyn, N. Y	"	66	12,200
1914	Rochester, N. Y	"	66 and 48	1,120
1915	Minneapolis, Minn	Lock-Bar and Riv.	40 and 48	7,355
1915	Ottawa, Ont	Lock-Bar	51	15,000
1916	Seattle, Wash	"	42	1,324
1916	Ottawa, Ont	"	51	1,945
1916	Minneapolis, Minn	Lock-Bar and Riv.	40 and 48	7,341
1916	Seattle, Wash	Lock-Bar	42	1,301
1916	Rochester, N. Y	"	37	50,754
1916	St. Louis, Mo	"	36	26,700
1916	Brandon, Vt	"	36	2,344
1916	Gary, Ind	"	36	1,865
1917	Eastman Kodak Co	"	42	7,910
1917	Rochester, N. Y	"	37	42,140
1917	Carnegie Natural Gas Co	"	54, 40, 36 and 30	48,537
1918	Carnegie Natural Gas Co	"	40	12,000
1919	Akron, Ohio	"	48	12,000
1919	Jersey City, N. J	"	72	88,000
1920	Elyria, Ohio	"	36	24,500
1920	Port Henry, Vermont	"	36 and 40	3,000
1920	Passaic Water Co	"	30	12,300
1920	Salt Lake City, Utah	"	36	1,200
1920	Bayonne, N. J	"	48	44,000
1920	Akron, Ohio	"	48	21,250
1920	Detroit, Michigan	"	48	21,930

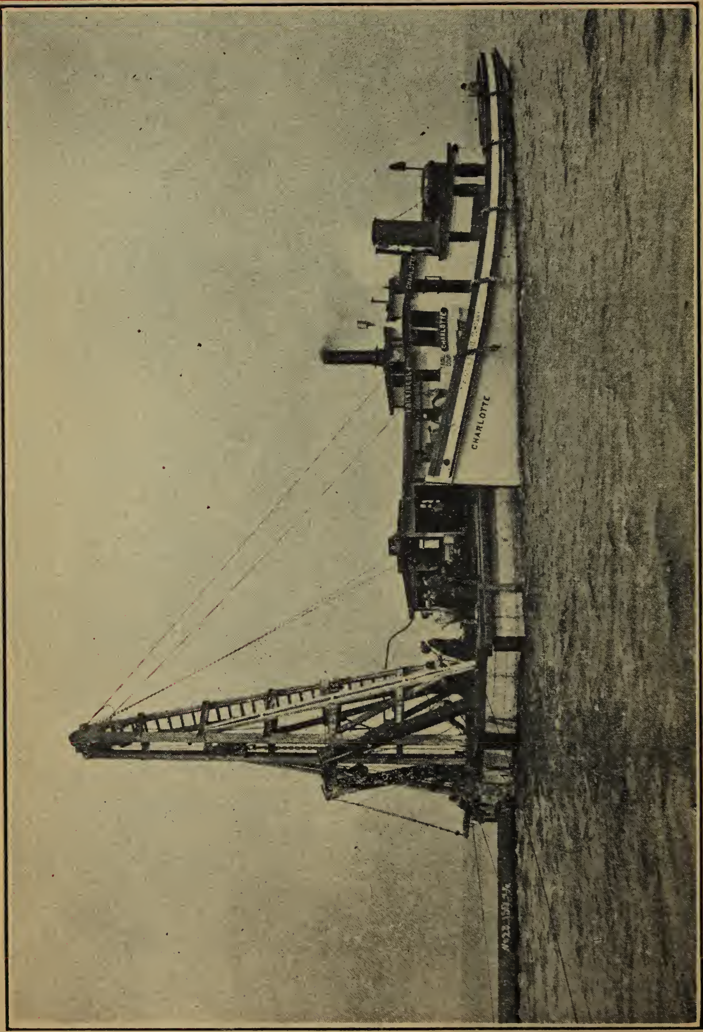


Fig. 59—SUBAQUEOUS LAYING OF LOCK-BAR PIPE

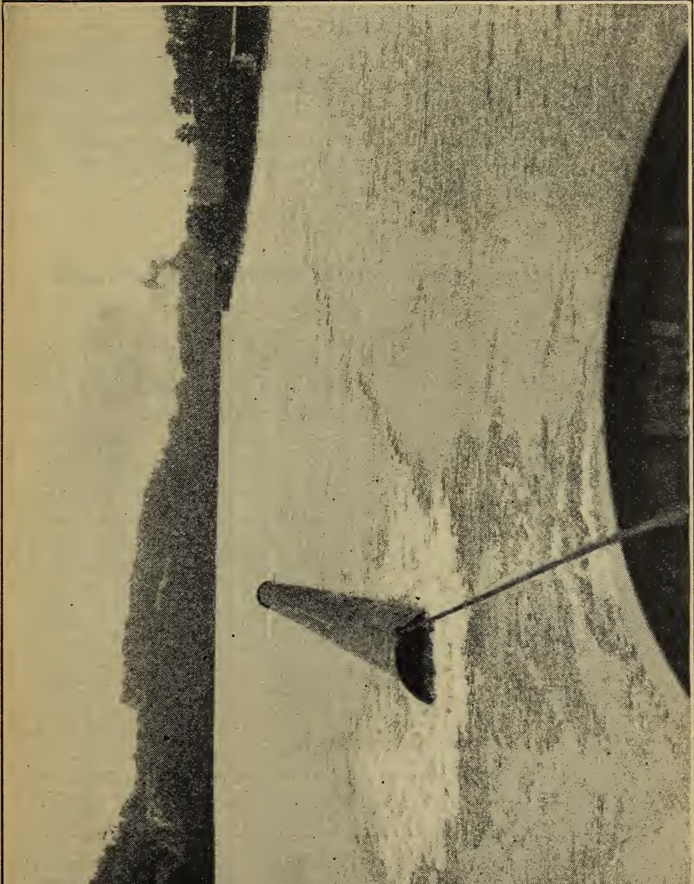


Fig. 60—TOWING LOCK-BAR PIPE INTO PLACE IN A SUBAQUEOUS LINE.

WATER

Water is composed of two gases, hydrogen and oxygen, in the ratio of two volumes of the former to one of the latter. It is never found pure in nature, owing to the readiness with which it absorbs impurities from the air and soil. Water boils under atmospheric pressure (14.7 pounds at sea level) at 212°, passing off as steam. Its greatest density is at 39.1°F., when it weighs 62.425 pounds per cubic foot.

Weight of Water per Cubic Foot at Different Temperatures

Temperature °F	Weight per cubic foot, pounds	Temperature °F	Weight per cubic foot, pounds	Temperature °F	Weight per cubic foot, pounds	Temperature °F	Weight per cubic foot, pounds	Temperature °F	Weight per cubic foot, pounds
32	62.42	150	61.18	260	58.55	380	54.36	500	48.7
40	62.42	160	60.98	270	58.26	390	53.94	510	48.1
50	62.41	170	60.77	280	57.96	400	53.5	520	47.6
60	62.37	180	60.55	290	57.65	410	53.0	530	47.0
70	62.31	190	60.32	300	57.33	420	52.6	540	46.3
80	62.23	200	60.12	310	57.00	430	52.2	550	45.6
90	62.13	210	59.88	320	56.66	440	51.7	560	44.9
100	62.02	212	59.83	330	56.30	450	51.2	570	44.1
110	61.89	220	59.63	340	55.94	460	50.7	580	43.3
120	61.74	230	59.37	350	55.57	470	50.2	590	42.6
130	61.56	240	59.11	360	55.18	480	49.7	600	41.8
140	61.37	250	58.83	370	54.78	490	49.2		

Volume of Water

Cent.	Fahr.	Volume	Cent.	Fahr.	Volume	Cent.	Fahr.	Volume
4°	39.1°	1.00000	35°	95°	1.00586	70°	158°	1.02241
5	41	1.00001	40	104	1.00767	75	167	1.02548
10	50	1.00025	45	113	1.00967	80	176	1.02872
15	59	1.00083	50	122	1.01186	85	185	1.03213
20	68	1.00171	55	131	1.01423	90	194	1.03570
25	77	1.00286	60	140	1.01678	95	203	1.03943
30	86	1.00425	65	149	1.01951	100	212	1.04332

WATER PRESSURE

(From Kent's Mechanical Engineers' Pocket Book.)

Comparison of Heads of Water in Feet with Pressures in Various Units

One foot of water at 39.1° F. =	62.425 pounds per square foot;
One foot of water at 39.1° F. =	0.4335 pound per square inch;
One foot of water at 39.1° F. =	0.0295 atmosphere;
One foot of water at 39.1° F. =	0.8826 inch of mercury at 30° F;
One foot of water at 39.1° F. =	773.3 feet of air at 32° F. and atmospheric pressure;

One pound on the square foot, at 39.1° F. =	0.01602 foot of water;
One pound on the square inch, at 39.1° F. =	2.307 feet of water;
One atmosphere of 29.922 inches of mercury =	33.9 feet of water;
One inch of mercury at 32° F. =	1.133 feet of water;
One foot of air at 32° F. and 1 atmosphere =	0.001293 foot of water;
One foot of average sea-water =	1.026 feet of pure water;
One foot of water at 62° F. =	62.355 pounds per square foot;
One foot of water at 62° F. =	0.43302 pound per square inch;
One inch of water at 62° F. = 0.5774 ounce =	0.036085 pound per square inch;
One pound of water on the square inch at 62° F. =	2.3094 feet of water;
One ounce of water on the square inch at 62° F. =	1.732 inches of water

Pressure of Water Due to Its Weight. The pressure of still water in pounds per square inch against the sides of any pipe, channel, or vessel of any shape whatever is due solely to the "head" or height of the level surface of the water above the point at which the pressure is considered, and is equal to 0.43302 pound per square inch for every foot of head, or 62.355 pounds per square foot for every foot of head (at 62°F.)

The pressure per square inch is equal in all directions, downwards, upwards, or sideways, and is independent of the shape or size of the containing vessel.

The pressure against a vertical surface, as a retaining-wall, at any point, is in direct ratio to the head above that point, increasing from o at the level surface to a maximum at the bottom. The total pressure against a vertical strip of a unit's breadth increases as the area of a right-angled triangle whose perpendicular represents the height of the strip and whose base represents the pressure on a unit of surface at the bottom; that is, it increases as the square of the depth. The sum of all the horizontal pressures is represented by the area of the triangle, and the resultant of this sum is equal to this sum exerted at a point one-third of the height from the bottom. (The center of gravity of the area of a triangle is one-third of its height.)

The horizontal pressure is the same if the surface is inclined instead of vertical.

The amount of pressure on the interior walls of a pipe has no appreciable effect upon the amount of flow.

Pressure in Pounds per Square Inch for Different Heads of Water

(At 62°F., 1 foot head = 0.433 pound per square inch; 0.433 X 144 = 62,352 pounds per cubic foot.)

Head, feet	0	1	2	3	4	5	6	7	8	9
0	......	0.433	0.866	1.299	1.732	2.165	2.598	3.031	3.464	3.897
10	4.330	4.763	5.196	5.629	6.062	6.495	6.928	7.361	7.794	8.227
20	8.660	9.093	9.526	9.959	10.392	10.825	11.258	11.691	12.124	12.557
30	12.990	13.423	13.856	14.289	14.722	15.155	15.588	16.021	16.454	16.887
40	17.320	17.753	18.186	18.619	19.052	19.485	19.918	20.351	20.784	21.217
50	21.650	22.083	22.516	22.949	23.382	23.815	24.248	24.681	25.114	25.547
60	25.980	26.413	26.846	27.279	27.712	28.145	28.578	29.011	29.444	29.877
70	30.310	30.743	31.176	31.609	32.042	32.475	32.908	33.341	33.774	34.207
80	34.640	35.073	35.506	35.939	36.372	36.805	37.238	37.671	38.104	38.537
90	38.970	39.403	39.836	40.269	40.702	41.135	41.568	42.001	42.434	42.867

Head in Feet of Water, Corresponding to Pressures in Pounds per Square Inch

1 pound per square inch = 2.30947 feet head; 1 atmosphere = 14.7 pounds per square inch = 33.94 feet head.)

Pressure, lbs.	0	1	2	3	4	5	6	7	8	9
0	....	2.309	4.619	6.928	9.238	11.547	13.857	16.166	18.476	20.785
10	23.0947	25.404	27.714	30.023	32.333	34.642	36.952	39.261	41.570	43.880
20	46.1894	48.499	50.808	53.118	55.427	57.737	60.046	62.356	64.665	66.975
30	69.2841	71.594	73.903	76.213	78.522	80.831	83.141	85.450	87.760	90.069
40	92.3788	94.688	96.998	99.307	101.62	103.93	106.24	108.55	110.85	113.16
50	115.4735	117.78	120.09	122.40	124.71	127.02	129.33	131.64	133.95	136.26
60	138.5682	140.88	143.19	145.50	147.81	150.12	152.42	154.73	157.04	159.35
70	161.6629	163.97	166.28	168.59	170.90	173.21	175.52	177.83	180.14	182.45
80	184.7576	187.07	189.38	191.69	194.00	196.31	198.61	200.92	203.23	205.54
90	207.8523	210.16	212.47	214.78	217.09	219.40	221.71	224.02	226.33	228.64

Ice and Snow. (From Clark.) 1 cubic foot of ice at 32° F. weighs 57.50 pounds; 1 pound of ice at 32° F. has a volume of 0.0174 cubic foot = 30.067 cubic inches.

Relative volume of ice to water at 32° F., 1.0855, the expansion in passing into the solid state being 8.55 per cent. Specific gravity of ice = 0.922, water at 62° F., being 1.

At high pressures the melting-point of ice is lower than 32° F., being at the rate of 0.0133° F. for each additional atmosphere of pressure.

Specific heat of ice is 0.504, that of water being 1.

1 cubic foot of fresh snow, according to humidity of atmosphere, weighs 5 pounds to 12 pounds. 1 cubic foot of snow moistened and compacted by rain weighs 15 pounds to 50 pounds (Trautwine).

Specific Heat of Water

(From Marks and Davis's Steam Tables.)

Degrees F.	Specific heat	Degrees F.	Specific heat	Degrees F.	Specific heat	Degrees F.	Specific heat	Degrees F.	Specific heat	Degrees F.	Specific heat
20	1.0168	120	0.9974	220	1.007	320	1.035	420	1.072	520	1.123
30	1.0098	130	0.9979	230	1.009	330	1.038	430	1.077	530	1.128
40	1.0045	140	0.9986	240	1.012	340	1.041	440	1.082	540	1.134
50	1.0012	150	0.9994	250	1.015	350	1.045	450	1.086	550	1.140
60	0.9990	160	1.0002	260	1.018	360	1.048	460	1.091	560	1.146
70	0.9977	170	1.0010	270	1.021	370	1.052	470	1.096	570	1.152
80	0.9970	180	1.0019	280	1.023	380	1.056	480	1.101	580	1.158
90	0.9967	190	1.0029	290	1.026	390	1.060	490	1.106	590	1.165
100	0.9967	200	1.0039	300	1.029	400	1.064	500	1.112	600	1.172
110	0.9970	210	1.0050	310	1.032	410	1.068	510	1.117		

Compressibility of Water. Water is very slightly compressible. Its compressibility is from 0.000040 to 0.000051 for one atmosphere, decreasing with increase of temperature. For each foot of pressure, distilled water will be diminished in volume 0.0000015 to 0.0000013. Water is so incompressible that even at a depth of a mile, a cubic foot of water will weigh only about half a pound more than at the surface.

FLOW OF WATER IN PIPES

The quantity of water discharged through a pipe depends on the head. If the discharge occurs freely into the air, this head is the difference in level between the surface of the water in the reservoir and the center of the discharge end of the pipe; if the lower end of the pipe is submerged, the head is the difference in elevation between the two water levels. The discharge for a given diameter depends also upon the length of the pipe, upon the character of its interior surface as to smoothness and upon the number and sharpness of its bends.

The head, instead of being an actual distance between levels, may be caused by pressure, as by pumping, in which case the head is calculated as a vertical distance corresponding to the pressure, 1 pound per square inch being equal to 2.309 feet head, or 1 foot head being equal to a pressure of 0.433 pound per square inch.

The total head operating to cause flow is divided into three parts: (1) The velocity head, which is the height through which a body must fall in a vacuum to acquire the velocity with which the water flows in the pipe. This is equal to $v^2 \div 2g$, in which v is the velocity in feet per second, and $2g = 64.32$; (2) The entry head, which is required to overcome the resistance to entrance to the pipe. With sharp-edged entrance the entry head equals about one-half of the velocity head; with smooth, rounded entrance the entry head is inappreciable; (3) The friction head, due to the frictional resistance to flow in the pipe.

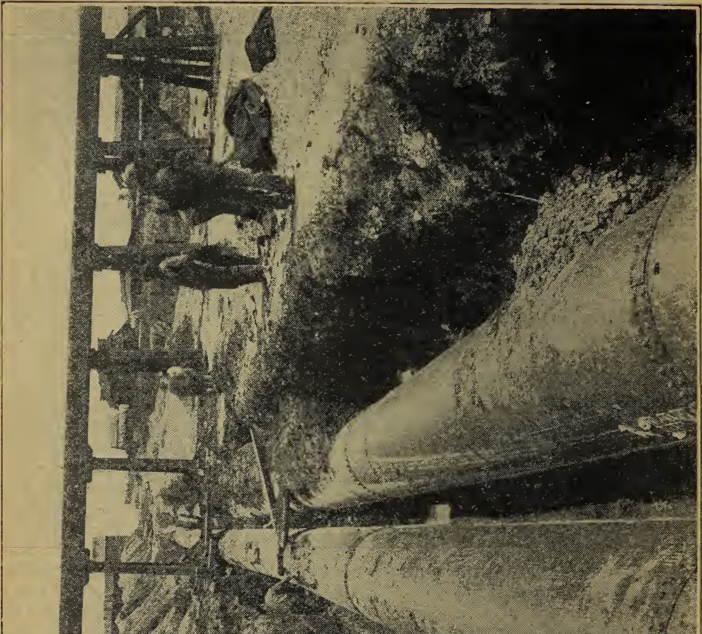


FIG. 61. TWIN LINES OF LOCK-BAR PIPE.

In ordinary cases of pipes of considerable length the sum of the entry and velocity heads scarcely exceeds one foot; in the case of long pipes with low heads it is so small that it may be neglected.

When the flow becomes steady, the pipe is entirely filled throughout its length, and hence the mean velocity at any section is the same as that at the end, when the size is uniform. This velocity is found to decrease as the length of the pipe increases, other things being equal, and becomes very small for great lengths, which shows that nearly all the head has been lost in overcoming the resistances. The length of the pipe is measured along its axis, following all the curves, if there be any. The velocity considered is the mean velocity, which is equal to the discharge divided by the area of the cross section of the pipe. The actual velocities in the cross section are greater than this mean velocity near the center and less than it near the interior surface of the pipe.

The object of the discussion of flow in pipes is to enable the discharge which will occur under given conditions to be determined, or to ascertain the proper size which a pipe should have in order to deliver a given discharge. The subject cannot, however, be developed with the definiteness which characterizes the flow from orifices and weirs, partly because the condition of the interior surface of the pipe greatly modifies the discharge, partly because of the lack of experimental data, and partly on account of defective theoretical knowledge regarding the laws of flow. In orifices and weirs errors of two or three per cent may be regarded as large with careful work; in pipes such errors are common, and are generally exceeded in most practical investigations.

It fortunately happens, however, that in most cases of the design of systems of pipes errors of five and ten per cent are not important, although they are of course to be avoided if possible, or, if not avoided, they should occur on the side of safety.

Quantity of Water Discharged

The quantity of water which flows through a pipe is the product of the area of its cross section and the mean velocity of flow. That is,

$$Q = av,$$

in which Q is the quantity discharged in cubic feet per second, a is the area in square feet and v is the velocity in feet per second.

For U. S. gallons per second multiply by	7.4805
For U. S. gallons per minute multiply by	448.83
For U. S. gallons per hour multiply by	26929.9
For U. S. gallons per 24 hours multiply by	646317.

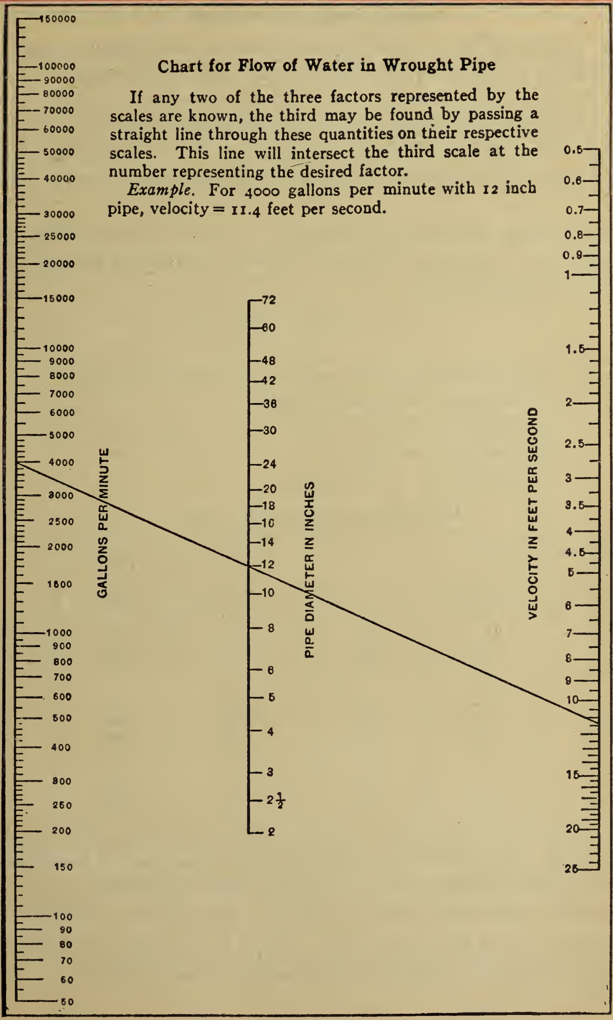
The diagram, page 123, gives the discharge in gallons per minute, when the velocity in the pipe line is known.

FIG. 62. INSTALLING A LOCK-BAR PIPE TWIN LINE THROUGH CITY STREETS

Chart for Flow of Water in Wrought Pipe

If any two of the three factors represented by the scales are known, the third may be found by passing a straight line through these quantities on their respective scales. This line will intersect the third scale at the number representing the desired factor.

Example. For 4000 gallons per minute with 12 inch pipe, velocity = 11.4 feet per second.



Mean Velocity of Flow

The velocity of flow, depending as it does to such a great extent upon the condition of the interior surface of the pipe, is difficult to compute. Below are given the formulæ most generally accepted. In the solution of any problem a comparison of the results obtained by the use of these formulæ is advisable. There are so many conditions affecting the flow of water that all hydraulic formulæ give only approximations to accurate results.

Approximate Formula (Trautwine). To find the velocity of water discharged from a pipe line, knowing the head, length and inside diameter, use the following formula:

$$v = m\sqrt{\frac{h\,D}{L + 54\,D}},$$

in which v = approximate mean velocity in feet per second;
m = coefficient from table below;
D = diameter of pipe in feet;
h = total head in feet;
L = total length of line in feet.

Values of Coefficient "m"

Diameter of Pipe		m	Diameter of Pipe		m
Feet	Inches		Feet	Inches	
0.1	1.2	23	1.5	18	53
0.2	2.4	30	2.0	24	57
0.3	3.6	34	2.5	30	60
0.4	4.8	37	3.0	36	62
0.5	6.0	39	3.5	42	64
0.6	7.2	42	4.0	48	66
0.7	8.4	44	5.0	60	68
0.8	9.6	46	6.0	72	70
0.9	10.8	47	7.0	84	72
1.0	12.0	48	10.0	120	77

The above coefficients are averages deduced from a large number of experiments. In most cases of pipes carefully laid and in fair condition, they should give results within 5 to 10 per cent of the truth.

Example: Given the head, $h = 50$ feet, the length, $L = 5280$ feet, and the diameter, $D = 2$ feet; to find the velocity and quantity of discharge.

The value of the coefficient m from the table when $D = 2$ feet is $m = 57$.

Substituting these values in the formula, we get:

$$v=57\sqrt{\frac{50\times2}{5280+108}}=57\sqrt{\frac{100}{5388}}=57\times0.136=7.752 \text{ feet per sec.}$$

To find the discharge in cubic feet per second, multiply this velocity by the area of cross section of the pipe in square feet.

Thus, $3.1416\times(1)^2\times7.752=24.35$ cubic feet per second.

Since there are 7.48 gallons in a cubic foot, the discharge in gallons per second $=24.35\times7.48=182.1$.

The above formula is only an approximation, since the flow is modified by bends, joints, incrustations, etc. Wrought pipes are smoother than cast-iron ones, thereby presenting less friction and less encouragement for deposits; and, being in longer lengths, the number of joints is reduced, thus lessening the undesirable effects of eddy currents.

Kutter's Formula. This formula, although originally designed for open channels, can be used in the case of long pipes with low heads. It is the joint production of two eminent Swiss engineers, E. Ganguillet and W. R. Kutter, and is, properly speaking, a formula for finding the coefficient C in the well-known Chezy formula:

$$v=C\sqrt{rs},$$

in which v = mean velocity in feet per second;
r = mean hydraulic radius in feet;
s = slope = head ÷ length.

The mean hydraulic radius is the area of wet cross-section divided by the wet perimeter, which for pipes running full, or exactly half full, is equal to one-quarter of the diameter.

According to Kutter the value of this coefficient C is

$$C=\frac{41.6+\dfrac{0.00281}{s}+\dfrac{1.811}{n}}{1+\left(4.16+\dfrac{0.00281}{s}\right)\times\dfrac{n}{\sqrt{r}}}$$

in which s is the slope, r is the mean hydraulic radius in feet and n is the "coefficient of roughness." The value of n varies from .010 for very smooth pipes to .015 for pipes in a very poor condition. For ordinary wrought pipe .012 can be used. For clean steel riveted pipe .015 can be used.

The following table gives values of the coefficient C as obtained by Kutter's formula for different slopes, hydraulic radii and degrees of roughness.

Table of Coefficient "C"

Coefficient "n"	Hydraulic radius in r feet										
	.1	.15	.2	.3	.4	.6	.8	1.0	1.5	2.0	3.0
	Slope $s = .0004$										
.009	104	116	126	138	148	157	166	172	183	190	199
.010	89	101	110	120	129	140	148	154	164	170	179
.011	78	90	97	107	115	126	133	138	148	154	162
.012	69	80	87	96	104	113	121	125	135	141	149
.013	62	71	78	87	94	103	110	115	124	130	138
.015	50	59	65	73	79	87	93	98	106	112	119
.017	43	50	54	62	68	75	81	85	93	98	105
	Slope $s = .0010$										
.009	110	121	129	141	150	161	169	175	184	191	199
.010	94	105	113	124	131	142	150	155	165	171	179
.011	83	92	99	109	117	127	134	139	149	155	163
.012	73	82	89	98	105	115	122	127	136	142	149
.013	65	74	81	89	96	104	111	116	124	130	138
.015	54	61	66	74	80	88	94	99	108	112	119
.017	45	51	57	63	69	76	82	86	93	98	105
	Slope $s = .0100$										
.009	110	122	130	143	151	162	170	175	185	191	199
.010	95	105	114	125	133	143	151	156	165	171	179
.011	83	93	100	111	119	129	135	141	149	155	162
.012	74	83	90	100	107	116	123	128	136	142	149
.013	66	75	81	90	98	106	112	117	125	130	138
.015	54	62	67	76	82	90	95	99	107	112	119
.017	46	52	57	64	70	77	82	87	94	99	105

For slopes steeper than .01 per unit of length, = 52.8 feet per mile, C remains practically the same as at that slope. But the velocity (being $C \times \sqrt{rs}$) of course continues to increase as the slope becomes steeper.

Darcy's Formula. The simplest form of Darcy's formula is

$$Cv^2 = Ds,$$

in which v is the velocity in feet per second, D is the diameter of the pipe in feet, s is the slope and C is a coefficient, varying with the diameter and roughness of the pipe. For cast-iron and wrought pipes of the same roughness, the values of C are given below. For rough pipe Darcy doubled the coefficient.

Values of "C" in Darcy's Formula

Diameter, inches	Rough pipe	Smooth pipe
3	0.00080	0.00040
4	0.00076	0.00038
6	0.00072	0.00036
8	0.00068	0.00034
10	0.00066	0.00033
12	0.00066	0.00033
14	0.00065	0.000325
16	0.00064	0.00032
24	0.00064	0.00032
30	0.00063	0.000315
36	0.00062	0.00031
48	0.00062	0.00031

Williams and Hazen's Exponential Formula. From Chezy's formula, $v = C\sqrt{rs}$, it would appear that the velocity varies as the square root of the head; this is not true, however, for C is not a constant, but a variable depending upon the roughness of the pipe and upon the hydraulic radius and the slope. Williams, and Hazen as a result of a study of the best records of experiments and plotting them on logarithmic ruled paper, ound an exponential formula $v = Cr^{0.63}\ s^{0.54}$, in which the coefficient C is practically independent of the diameter and the slope, and varies only with the condition of the surface. In order to equalize the numerical value of C to that of the C in the Chezy formula, at a slope of 0.001, they added the factor $0.001^{-0.04}$ to the formula, so that the working formula of Williams and Hazen is

$$v = Cr^{0.63}s^{0.54}0.001^{-0.04}.$$

The value of C varies to a great extent, depending on the condition of the interior of the pipe. A fair value for iron or steel pipe is $C = 100$. Computations of the exponential formula are made by logarithms or by the Williams-Hazen hydraulic slide rule.

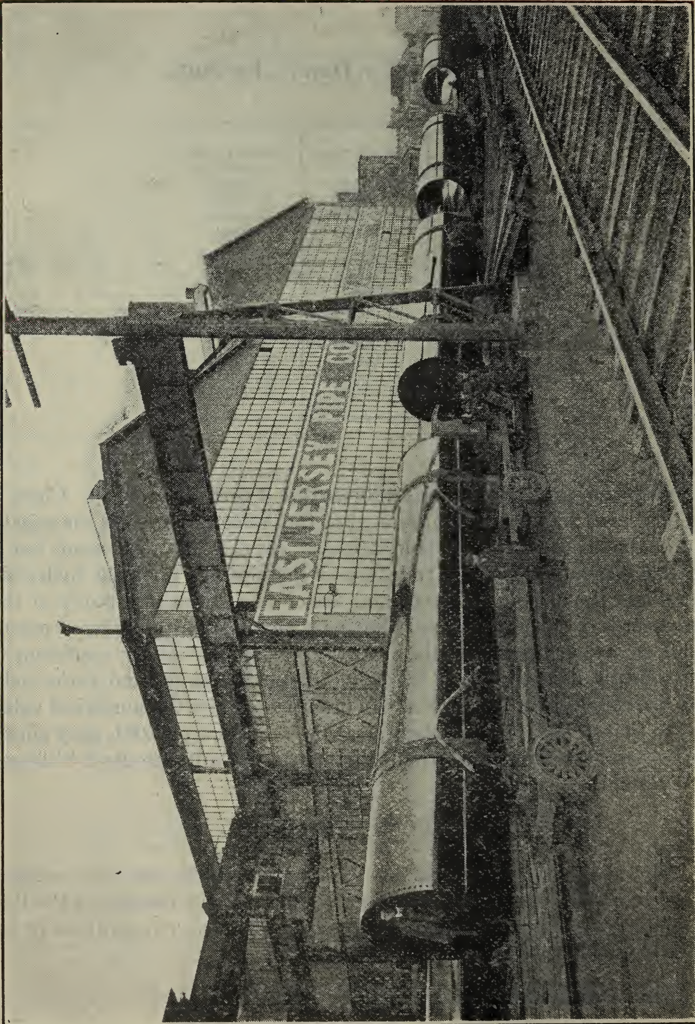


FIG. 36. SHIPMENT OF LOCK-BAR PIPE FOR JERSEY CITY

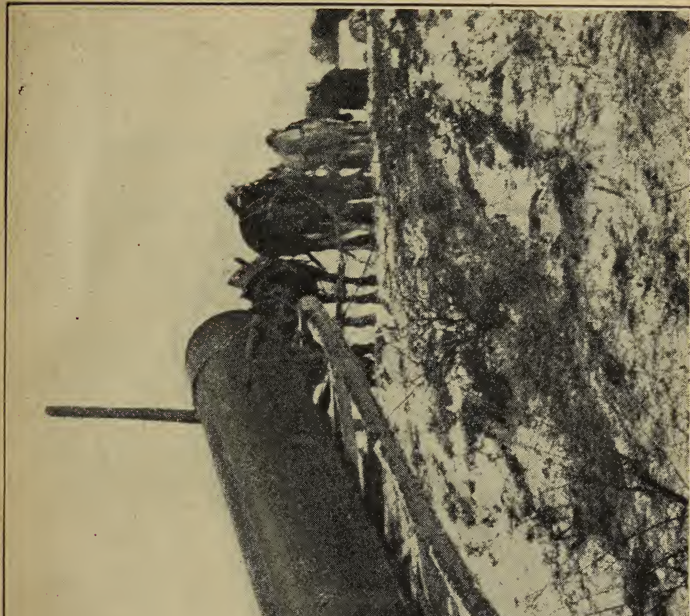


FIG. 64 TRANSPORTING LOCK-BAR PIPE ON SKIDS

Hydraulic Grade-line. In a straight tube of uniform diameter throughout, running full and discharging freely into the air, the hydraulic grade-line is a straight line drawn from the discharge end to a point immediately over the entry end of the pipe, and at a depth below the surface equal to the entry and velocity heads (Trautwine).

In a pipe leading from a reservoir, no part of its length should be above the hydraulic grade-line.

Air-bound Pipes. A pipe is said to be air-bound when, in consequence of air being entrapped at the high points of vertical curves in the line, water will not flow out of the pipe, although the supply is higher than the outlet. The remedy is to provide cocks or valves at the high points, through which the air may be discharged. The valve may be made automatic by means of a float.

Water Hammer. When a valve in a pipe is closed while the water is flowing, the velocity of the water behind the valve is retarded and a dynamic pressure is produced. When the valve is closed quickly this dynamic pressure may be much greater than that due to the static pressure, and it is then called "water hammer" or "water ram." This action is dangerous and causes in many cases fracture of the pipe. It is provided against by arrangements which prevent a rapid closing of the valve. The formulæ for the pressure produced by this shock are

$$p = 0.027 \frac{lv}{t} - po + p1, \tag{1}$$

$$p = 63v - po + p1, \tag{2}$$

where po = the static pressure when there is no flow, $p1$ = the static pressure when the flow is in progress, p = the maximum dynamic pressure due to the water hammer in excess over the pressure po, v = the velocity in feet per second, l = length of pipe back from the valve in feet, and t = time of closing of valve in seconds. The pressures in the formulæ are expressed in pounds per square inch. Formula (1) is to be used when t is greater than 0.000428 l and formula (2) when t is equal to or less than this.

From the first of these formulæ the value of t when $p = o$ is found to be

$$t = 0.027 \frac{lv}{po - p1},$$

which is the time of valve closing in order that there may be no water hammer. To prevent the effects of water hammer, it is customary to arrange valves so that they cannot be closed very quickly, and the last formula furnishes the means of estimating the time required in order that no excess of dynamic pressure over the static pressure po may occur.

Formulas for Long Pipes

The Chezy Formula. If v is the velocity in the pipe, C a coefficient dependent upon roughness, density, velocity, and diameter, r the Hydraulic, Radius, namely the cross-sectional area divided by the wetted perimeter, hf the frictional loss of head in a length L, and if h_f/L be designated by s the inclination or slope, then

$$v = C\sqrt{rh_f/L} \quad \text{or} \quad v = C\sqrt{rs}$$

in which for new pipes C ranges from 95 to 152 and for old pipes from 60 to 120, the value increasing both with the diameter and the velocity, as shown in the following tables.

Values of "C" in Chezy Formula for Cast-iron Pipes

Diameter of pipe, inches	Velocities in feet per second							
	For new pipes				For old pipes			
	1	3	6	10	1	3	6	10
3	95	98	100	102	63	68	71	73
6	96	101	104	106	69	74	77	79
9	98	105	109	112	73	87	80	84
12	100	108	112	117	77	82	85	88
15	102	110	117	122	81	86	89	91
18	105	112	119	125	86	91	94	97
24	111	120	126	131	92	98	101	104
30	118	126	131	136	98	103	106	109
36	124	131	136	140	103	108	111	114
42	130	136	140	144	105	111	114	117
48	135	141	145	148	106	112	115	118
60	142	147	150	152	...	...	...	...

For steel riveted pipes see next page. Chezy's formula is also used for conduits and streams by the coefficient C for such cases is generally expressed in terms of r and s

Darcy's Formula. The original form of Darcy's equation was $rs = av + bv^2$, where a and b were coefficients. This Darcy later reduced to $rs = Cv^2$, where $C = c_1 + c_2 fr$. where c_1 and c_2 are constants. For new cast-iron and for wrought-iron pipes of the same roughness, Darcy's values of these

Values of "*C*" in Chezy Formula for Steel Riveted Pipes

Diameter of pipes, inches	Velocity in ft. per second			
	1	3	5	10
3	81	86	89	92
11	92	102	107	115
11	93	99	102	105
15	109	112	114	117
38	113	113	113	113
42	102	106	108	111
48	105	105	105	105
72	110	110	111	111
72	93	101	105	110
103	114	109	106	104

constants are $c_1 = 0.0000773$ and $c_2 = 0.00000162$. The formula then reduces to

$$hf = 0.00000647 \frac{(12\,D+1)}{D} \frac{v^2 L}{r} \quad or \quad v = 394 \sqrt{\frac{D}{12\,D+1}} \sqrt{rs}$$

where D is the diameter of the pipe in feet. For rough pipe Darcy reduced the velocity one-half. Darcy's formula may be transposed to $CV^2 = Ds$, in which case C has an average value of 0.00032 for clean pipes of diameters from 8 to 48 inches inclusive, the variation being only 3% from the mean for all except the 8-inch. The table on page 127 gives more accurate values of C for Darcy's formula in the last form.

Fanning's formula for flow in pipes is

$$h_f = \frac{4fL}{D} \frac{v^2}{2\,g} \quad \text{or} \quad v = \sqrt{\frac{2\,gDh_f}{4fL}}$$

where f is a coefficient which ranges from 0.0071 to 0.0028 for new pipes and from 0.0152 to 0.00046 for old ones, the value decreasing as diameter and velocity increase. The other notation is the same as that at the beginning of this article.

Values of *f* in Fanning's Formula for Cast-iron Pipes

Diameter of pipe, inches	Velocity in feet per second							
	For new pipes				For old pipes			
	1	3	6	10	1	3	6	10
3	.0071	.0067	.0064	.0062	.0152	.0139	.0128	.0122
6	.007	.0063	.006	.0057	.0135	.0117	.0108	.0103
9	.0067	.0058	.0055	.0051	.0122	.0105	.010	.0092
12	.0064	.0056	.0051	.0048	.0108	.0096	.0089	.0084
15	.0062	.0053	.0048	.0043	.0099	.0087	.0081	.0078
18	.0058	.0051	.0045	.0041	.0087	.0078	.0073	.0069
24	.0053	.0045	.0040	.0037	.0076	.0067	.0063	.0060
30	.0046	.0040	.0037	.0035	.0067	.0061	.0057	.0055
36	.0042	.0037	.0035	.0033	.0061	.0056	.0052	.0050
42	.0038	.0035	.0033	.0031	.0058	.0052	.005	.0048
48	.0036	.003	.0031	.0029	.0057	.0051	.0049	.0046
60	.0032	.0030	.0029	.0028				

Tables for Long Pipes are given on the three following pages. The friction factors $4f$ used in computing them differ slightly from those at the foot of the preceeding page and are the same as those given in "Merriman's Treatise on Hydraulics." These tables apply to new, clean, straight cast-iron and wrought-iron pipes, either smooth or coated with coal tar, and laid with close joints. A pipe is said to be long when its length is such that the error in computing v by the last formula does not exceed five percent; this will usually be the case when the length of the pipe is greater than 1000 diameters.

The discharges given in the tables are accurate in the last figure for the given velocities. Thus for a velocity of 3.4 ft. per sec. the discharges for pipes 6 and 16 in. in diameter are 40.1 and 285 cu. ft. per min. The friction head, given in the second column under each size of pipe, is however liable to an error of one or two units in the second figure; thus for 3.4 ft. per sec., in the 6-inch pipe the head 0.88 per 100 ft. may actually range from 0.86 to 0.90 for new, clean pipes.

Velocities and Discharges for a given pipe may be found from the tables when the friction head is known. For example, let a pipe 3500 ft. long and 6 in. in diameter have a total head of 37.8 ft. Here the friction head per 100 ft. is 100X378/3500 =1.08, whence from the table velocity =3.8 ft. per sec., and discharge =44.8 cu. ft. per min. Again, let an 8 -in. pipe 6075 ft. long be under a head of 112.5 ft. then friction head per 100 ft. is 100x-112.5/6075=1.85, whence velocity=6.1 ft. per sec., and discharge=199 cu. ft. per sec. These are for new, clean, straight iron pipes. Curves influence results but little unless they are very sharp.

For Old Pipes the actual heads should be multiplied by the following numbers before using the table to obtain velocities and discharges:

For diameter,	3	6	12	16	24	30	36 in.
Multiplier.....	0.50	0.55	0.60	0.62	0.64	0.65	0.66

For example, let an old pipe 3500 ft. long and 6 in. diameter be under an actual head of 37.8 ft. or 1.08 ft. per 100 ft; the true friction head is 0.55X1.08 =0.59 ft. per 100 ft., whence from the table velocity =2.8 ft. per sec. and discharge =33 cu. ft. per sec. Similarly, for given velocities the true friction heads are found approximately by multiplying the tabular values by the following numbers:

For diameter,	3	6	12	16	24	30	36 in.
Multiplier.....	2.00	1.81	1.67	1.61	1.56	1.54	1.52

For example, for a velocity of 60 ft. per sec. the friction head in an old pipe of 12 in. diameter is 1.87 instead of 1.12 ft. per 100 ft. The term old pipe is a vague one, and refers to the amount of corrosion and incrustation rather than to the actual life in years.

The Required Diameter for a pipe to furnish a given discharge under a given head may also be roughly found from the tables. For example, to find diameter to furnish 100 cu. ft. min. under a head of 1.2 ft. per 100 ft: for a new, clean pipe the tables give 8 inches as required diameter, for an old pipe, assume multiplier as 0.5, then head becomes, 0.60 ft. per 100 ft. and the table shows that a 10-in. pipe is somewhat too large.

The formula for computing the diameter of a long pipe is: $D = 0.479\ (4flq^2/h^{1/5})$, in which q =discharge in. cu. ft. per min., h =head in ft., l =length of pipe in ft. D =diameter of pipe in ft., and a rough mean value of f being taken as 0.005 for new pipe. After D is computed the velocity is found by $v = q/\frac{1}{4}\pi D2$ and thus a better value of f may be obtained from the table at foot of page preceding. Then a new diameter may be re-computed if the change in f seems to warrant it.

For example, to find the diameter of a new pipe to deliver 67 cu. ft. per sec. under a head of 24 ft. its length being 4500 ft. Using $4f$ as 0.020, the formula gives D =3.35 ft., whence v =6.6 ft. per sec. Then from the table at foot of preceding page a closer value of f is found to be 0.0061, or $4f$ =0.025. A second computation now gives D =3.52 ft. so that a 42-inch pipe should be used. With the same data the rough value of $4f$ for an old pipe is 0.035 and D is about 48 inches.

Kutter. The Kutter formula was designed for open channels and will be treated under that head. It is sometimes used for pipes, but the results from it, since the coefficients, like those of the Chezy and Fanning formulas, change with the velocity in the same pipe, are usually erroneous, except for a very small range of velocity. For this reason it is not to be recommended for general use in computations for pipes.

Exponential Formula for Pipes

One form of an exponential formula for flow of water in pipes is

$$h_f = Kv^N L/D^{1\ 25}$$

where the notation is the same as that at beginning of page 135, but where the coefficients K and N may vary with the kind and condition of the pipe. To avoid zeros in the coefficient a unit length of 1000 feet may be taken, when the formula becomes

$$h_f = \frac{Kv^N}{D^{1 \cdot 25}} \cdot \frac{L}{1000}$$

in which N has a mean value of 1.87 and K ranges from 0.28 to 0.48 with an average value of 0.38 for ordinarily clean pipes. For rough or tuberculated pipes K may become as high as 0.70. The advantage of the exponential formula is that the coefficient for the same pipe is nearly constant and, if the exponent, its range being from 1.70 to 2.00,be properly selected, absolutely so, and the variation in all cases is much less than with other formulas, so that with a few average coefficients for different classes of channels, all hydraulic flow problems may be solved with reasonable accuracy without reference to any tables of coefficients. The foregoing formula with the coefficient 0.38 may be expected to give results within 20% of accuracy for any pipes likely to be encountered which have diameters from one inch to fifteen feet, except those extremely tuberculated, and with velocities from 1 foot to 20 feet per second. For ordinary cast-iron or riveted pipe with any diameter and velocity, the results may be expected to be within 6% of accuracy.

The exponential formula is derived from experiment in the following manner: Any plane curve passing through the origin of coordinates can be represented by an equation of the form $y = mx^N$, in which m and N may be either constant or variable. If the curve be one of single curvature such that the change of inclination of its tangents either continuously increases or continuously decreases, both m and N become constants. All curves which are loci of equations expressing the relation between velocity and loss of head in flowing water are of this latter class, and consequently $hf = mv^N$ is a general expression for the loss of head in either a pipe or an open channel. If for any pipe line the values of m and N be determined, the equation of flow in that line is established. Expressing the above equation for logarithmic computation, it becomes

$$\log h_f = \log m \div N \log v$$

and considering the logarithms as mere quantities, this is at once seen to be the equation of a straight line in which $\log m$ is the intercept on the hf axis and N is the tangent of the angle which the line makes with the v axis. Both m and N may be found by determining two points in the line representing the plottings of the logarithms. If it be desired to draw the straight line which most nearly coincides with a number of points, it must pass through their center of gravity and also through the centers of gravity of the two groups into which the center of gravity of the whole divides them. Having the last two points, the equation of the line is readily determined.

The following example will serve to illustrate the process (Fig. 65). The data are from observations on a 12-inch cast-iron water main very carefully laid in a tangent some 3500 feet long, the loss in 1000 feet of which was measured.

C = center of gravity or mean point of the whole group
A = center of gravity of part of group above C
B = center of gravity of part of group below C
$Ch = hf$ coordinate of C, $Cv = v$ coordinate of C
$Ah = hf$ coordinate of A, $Av = v$ coordinate of A
$Bh = hf$ coordinate of B, $Bv = v$ coordinate of B

Observed Data

No.	v Ft. per sec	hf Ft of water	log v		log hf	
1	4.794	6.515	0.6807		0.8139	
2	4.667	5.577	.6690	Sum = 3.1667	.7464	Sum = 3.4641
3	4.155	5.100	.6186	mean = 0.63334	.7076	mean = 0.69282
4	3.998	4.002	.6018	= Av	.6023	= Ah
5	3.950	3.926	.5966		.5939	
6	3.519	3.566	.5464		.5522	
7	3.252	2.888	.5122	Sum = 2.3715	.4606	Sum = 2.0046
8	3.208	2.942	.5062	mean = 0.47430	.4686	Mean = 0.40092
9	2.943	2.374	.4688	= Bv	.3755	= Bh
10	2.177	1.405	.3379		.1477	

Sum = 5.5382   Sum = 5.4687
mean = 0.55382 = Cv mean = 0.54687 = Ch

$Av—Cv = 0.63334—0.55382 = 0.07952$ $Ah—Ch = 0.69282—0.54687 = 0.14595$
$Cv—Bv = 0.55382—0.47430 = 0.07952$ $Ch—Bh = 0.54687—0.40092 = 0.14595$

Since $Av—Cv = Cv—Bv$ and $Ah—Ch = Ch—Bh$, the three points A, C, and B are in a straight line, which fact checks the accuracy of the work.

N = tangent of inclination of line ACB

$$= \frac{Ah\text{-}Ch}{Av\text{-}Cv} = \frac{Ch\text{-}Bh}{Cv\text{-}Bv} = \frac{Ah\text{-}Bh}{Av\text{-}Bv} = \frac{0.14592}{0.07952} = 1.835$$

Since log m = log hf—n log v, using the coordinates of C
log m = 0.54687—1.835X0.55382
= 0.54687—1.01626 = 9.53051 = log 0.3393, and m = 0.3393

The equation for this 12-inch pipe is therefore $hf = 0.3393\ v1.835\ L/1000$.

Remark: Evidently the v coordinates must be divided between the same pair of observations as the hf coordinates. The mathematical determination of what group should include a point whose v coordinate is on one side of C and whose hf coordinate is on the other, depends on whether the point itself is above or below a normal to the line ACB through C. This can usually be established by plotting the logarithms on ordinary cross-section paper, or the observations on logarithmic paper.

To introduce the diameter into the equation, a series of values of m and N for pipes of different diameters must be obtained. The range of N is relatively small, the limits for all reliable pipe experiments on record being from 1.70 to 2.08, and if the pipes are of the same character of surface and alignment the value of N will be constant. It is, therefore, only necessary to consider the variation of m, which depends upon the area of the cross-section or upon D and upon the roughness. Evidently m varies inversely as some power of the diameter, and for $1/D = o$, $m = o$ for any velocity, so the curve representing the relation between m and D will be $m = KD—x$. Proceeding in the same manner as before an average value of $x = 1.25$ will be obtained, and the formula for pipe of the same character as that in the above experiment is

$$hf = \frac{Kv^{1835}}{D^{1\cdot 25}} \cdot \frac{L}{1000} \quad \text{or} \quad hf = \frac{0.38v^{187}}{D^{1\cdot 25}} \cdot \frac{L}{1000}$$

for average conditions, and this may be transposed to

$$v = 73.54\,D^{0\cdot 668}\,S^{0\cdot 535} \quad \text{or} \quad v = 185\,r^{0\cdot 668}s^{0\cdot 535}$$

Variations in Diameter

Relation of Diameter of Pipe to Quantity Discharged. In terms of C for Chezy's formula.

$$Q = \pi/8C\sqrt{sD^5}$$

in terms of Fanning's coefficient f, $Q = \pi/4\sqrt{\frac{2g}{4f} \cdot \frac{hf}{L} \cdot D^5}$

Approximately for rough pipe $Q = 1000\ D^{5/2}s^{1/2}$

and for smooth pipe $Q = 2 \times 1000\ D^{5/2}s^{1/2}$

Roughness. The effect of roughness in a water pipe is in general to retard the flow or increase the loss in head. This is accomplished by reducing the velocity of the water at the surface of contact, thus producing a general reduction in velocity and also causing cross currents or eddies which use up the energy in the stream. Roughness decreases C and increases f and K in the foregoing formulas. It also increases N somewaht in the exponential formula.

Curvature. The effect of curvature is to increase the loss of head. This increased loss is partly due to the cross currents and eddies set up in the bend, but also to the changes of velocity along the stream lines and increased friction along the walls of the channels due to increased velocities over part of the circumference. The loss of head due to a curve may be stated in terms of the velocity head h_v or, better, in terms of the equivalent length of straight pipe which would give the same loss as the curve. Experiments upon the loss of head in pipes show the radius of the curve of minimum resistance for a right-angled bend to be about three diameters of the pipe. For six-inch pipe the loss due to such a curve is about the same as that in eight feet of straight pipe, and for a thirty-inch pipe about the same as that in forty feet of straight pipe. For intermediate sizes the loss may be expected to fall between these limits and to vary approximately as the diameter.

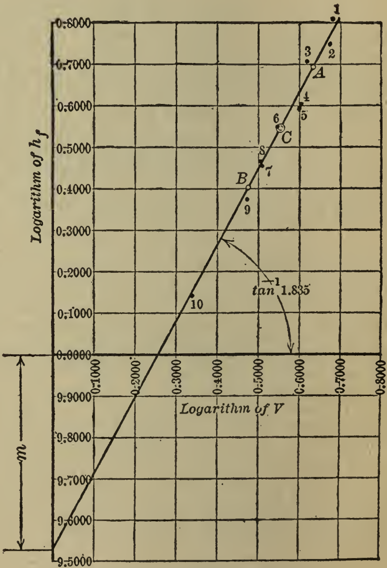


Fig. 65. Logarithmic Plotting

Expansions when sudden always produce eddies which increase the loss of head. Consider two sections of a pipe, 1 and 2; 1 to be taken at a point where normal condition of flow exists before expansion and 2 after expansion.

If v_1 and v_2 are the velocities and A_1 and A_2 the areas at the two sections then the loss of head due to this sudden enlargement

$$hfe = \frac{(v_1 - v_2)^2}{2g} \text{ or } hfe = \left[\frac{A_2}{A_1} - 1\right]^2 \frac{v_2^2}{2g}$$

According to St. Venant, this quantity should be increased by $v^2/18\,g$, but this correction is so small as a rule that it can be neglected, and more recent experiments indicate that the formula is as likely to give results in excess as otherwise.

Contraction when sudden produces an effect upon a stream very similar to a sharp orifice; that is, just beyond the contraction occurs the point of minimum cross-section of the stream or the "vena contracta." There result not only the loss of head due to the contraction of the stream, but also that due to the reenlargement of it after passing the "vena contracta." If v is the velocity under conditions of normal flow in the pipe after passing the contraction and C is the coefficient of contraction, the same in this case as for a sharp orifice, then the loss of head due to the contraction is

$$hfc = \frac{v^2}{2g}\left[\frac{1}{C} - 1\right]^2$$

According to St. Venant this quantity should be increased by $v^2/18\,g$. Also it may be written $hfc = Ccv^2/2\,g$, where Cc varies from 0.42 to 0.53. A fair assumption to make is $Cc = 0.5$. This may also be taken as the loss of head due to sharp-edged entrance into a pipe. The value of C is probably too high for small pipes and too low for large pipes.

Obstructions. If the sectional area of a pipe be gradually decreased and then gradually increased as in the case of a Venturi meter, the loss of head for moderate velocities is not much increased over that due to normal flow. When the obstruction causes a sudden contraction or expansion of the stream or there is discontinuity of the pipe wall, the loss of head is increased.

Valves. The losses due to valves in pipe lines have been investigated with accuracy in only a few instances. From these experiments it appears that a fully open gate valve in a pipe causes a loss of head corresponding to about six diameters of length of the pipe.

MEASUREMENT OF FLOWING WATER

(From Kent's Mechanical Engineers' Pocket Book.)

Piezometer. If a vertical or oblique tube be inserted into a pipe containing water under pressure, the water will rise in the former, and the vertical height to which it rises will be the head producing the pressure at the point where the tube is attached. Such a tube is called a piezometer or pressure measure. If the water in the piezometer falls below its proper level it shows that the pressure in the main pipe has been reduced by an obstruction between the piezometer and the reservoir. If the water rises above its proper level it indicates that the pressure there has been increased by an obstruction beyond the piezometer.

If we imagine a pipe full of water to be provided with a number of piezometers, then a line joining the tops of the columns of water in them is the hydraulic grade-line.

Pitot Tube. The Pitot tube is used for measuring the velocity of fluids in motion. It has been used with great success in measuring the flow of natural gas. (S. W. Robinson, Report Ohio Geol. Survey, 1890.) (See also Van Nostrand's Mag., Vol. XXXV.) It is simply a tube so bent that a short leg extends into the current of fluid flowing from a tube, with the plane of the entering orifice opposed at right angles to the direction of the current. The pressure caused by the impact of the current is transmitted through the tube to a pressure-gage of any kind, such as a column of water or of mercury, or a Bourdon spring-gage. From the pressure thus indicated and the known density and temperature of the flowing fluid is obtained the head corresponding to the pressure, and from this the velocity. In a modification of the Pitot tube described by Professor Robinson, there are two tubes inserted into the pipe conveying the gas, one of which has the plane of the orifice at right angles to the current, to receive the static pressure plus the pressure due to impact; the other has the plane of its orifice parallel to the current so as to receive the static pressure only. These tubes are connected to the legs of a U tube partly filled with mercury, which then registers the difference in pressure in the two tubes, from which the velocity may be calculated. Comparative tests of Pitot tubes with gas-meters, for measurement of the flow of natural gas, have shown an agreement within 3%.

It appears from experiments made by W. M. White, described in a paper before the Louisiana Eng's Socy., 1901, by Williams, Hubbell and Fenkel (Trans, A. S. C. E., 1901), and by W. B. Gregory (Trans, A. S. M. E., 1903), that in the formula for the Pitot tube, $V = c\sqrt{2gH}$, in which V is the velocity of the current in feet per second, H the head in feet of the fluid corresponding to the pressure measured by the tube, and c an experimental coefficient, $c = 1$ when the plane at the point of the tube is exactly at right angles with the direction of the current, and when the static pressure is correctly measured. The total pressure pro-

duced by a jet striking an extended plane surface at right angles to it, and escaping parallel to the plate, equals twice the product of the area of the jet into the pressure calculated from the "head due to the velocity," and for this case $H = 2 \times \frac{V^2}{2g}$, instead of $\frac{V^2}{2g}$; but as found in White's experiments the maximum pressure at the point on the plate exactly opposite the jet corresponds to $h = \frac{V^2}{2g}$. Experiments made with four different shapes of nozzles placed under the center of a falling stream of water showed that the pressure produced was capable of sustaining a column of water almost exactly equal to the height of the falling water.

Tests by J. A. Knesche (Indust. Eng'g, Nov., 1909), in which a Pitot tube was inserted in a 4-inch water pipe, gave C = about 0.77 for velocities of 2.5 to 8 feet per second, and smaller values for lower velocities. He holds that the coefficient of a tube should be determined by experiment before its readings can be considered accurate.

Maximum and Mean Velocities in Pipes. Williams, Hubbell and Fenkel (Trans. A. S. C. E., 1901) found a ratio of 0.84 between the mean and the maximum velocities of water flowing in closed circular conduits, under normal conditions, at ordinary velocities; whereby observations of velocity taken at the center under such conditions, with a properly rated Pitot tube, may be relied on to give results within 3% of correctness.

The Venturi Meter, invented by Clemens Herschel, and described in a pamphlet issued by the Builders' Iron Foundry of Providence, R. I., is named for Venturi, who first called attention, in 1796, to the relation between the velocities and pressures of fluids when flowing through converging and diverging tubes. It consists of two parts,—the tube, through which the water flows, and the recorder, which registers the quantity of water that passes through the tube. The tube takes the shape of two truncated cones joined in their smallest diameters by a short throat-piece. At the up-stream end and at the throat there are pressure-chambers, at which points the pressures are taken.

The action of the tube is based on that property which causes the small section of a gently expanding frustum of a cone to receive, without material resultant loss of head, as much water at the smallest diameter as is discharged at the large end, and on that further property which causes the pressure of the water flowing through the throat to be less, by virtue of its greater velocity, than the pressure at the up-stream end of the tube; each pressure being at the same time a function of the velocity at that point and of the hydrostatic pressure which would obtain were the water motionless within the pipe.

The recorder is connected with the tube by pressure-pipes which lead to it from the chambers surrounding the up-stream end and the throat of the tube. It may be placed in any convenient position within 1000 feet of the meter. It is operated by a weight and clockwork. The difference of pressure or head at the entrance and at the throat of the meter is balanced in the recorder by the difference of level in two columns of mercury in cylindrical receivers, one within the other. The inner carries a float, the position of which is indicative of the quantity of water flowing through the tube. By its rise and fall the float varies the time of contact between an integrating drum and the counters by which the successive readings are registered.

There is no limit to the sizes of the meters nor the quantity of water that may be measured. Meters with 24-inch, 36-inch, 48-inch, and even 20-foot tubes can be readily made.

Measurement by Venturi Tubes (Trans. A. S. C. E., Nov., 1887. and Jan., 1888). Mr. Herschel recommends the use of a Venturi tube inserted in the force main of the pumping engine, for determining the quantity of water discharged. Such a tube applied to a 24-inch main has a total length of about 20 feet. At a distance of 4 feet from the end nearest the engine the inside diameter of the tube is contracted to a throat having a diameter of about 8 inches. A pressure gage is attached to each of two chambers, the one surrounding and communicating with the entrance or main pipe, the other with the throat. According to experiments made upon two tubes of this kind, one 4 inches in diameter at the throat and 12 inches at the entrance, and the other about 36 inches in diameter at the throat and 9 feet at its entrance, the quantity of water which passes through the tube is very nearly the theoretical discharge through an opening having an area equal to that of the throat, and a velocity which is that due to the difference in head shown by the two gages. Mr. Herschel states that the coefficient for these two widely varying sizes of tubes, and for a wide range of velocity through the pipe, was found to be within 2%, either way, of 98%. In other words, the quantity of water flowing through the tube per second is expressed within two per cent by the formula $W = 0.98\, A\sqrt{2\,gh}$, in which A is the area of the throat of the tube, h the head, in feet, corresponding to the difference in the pressure of the water entering the tube and that found at the throat, and $g = 32.16$.

THE MINER'S INCH

(From Merriman's Treatise on Hydraulics.)

The miner's inch may be roughly defined to be the quantity of water which will flow from a vertical standard orifice one inch square, when the head on the center of the orifice is 6½ inches. The coefficient of discharge is about 0.623, and accordingly the actual discharge from the orifice in cubic feet per second is

$$q=\frac{1}{144}\times 0.623\times 8.02\sqrt{\frac{6.5}{12}}=0.0255,$$

and the discharge in one minute is 60x0.0255 = 1.53 cubic feet. The mean value of one miner's inch is therefore about 1.5 cubic feet per minute.

The actual value of the miner's inch, however, differs considerably in different localities. Bowie states that in different counties of California it ranges from 1.20 to 1.76 cubic feet per minute. The reason for these variations is due to the fact that when water is bought for mining or irrigating purposes, a much larger quantity than one miner's inch is required, and hence larger orifices than one square inch are needed. Thus at Smartsville, a vertical orifice or module, 4 inches deep and 250 inches long, with a head of 7 inches above the top edge, is said to furnish 1000 miner's inches. Again at Columbia Hill, a module 12 inches deep and 12¾ inches wide, with a head of 6 inches above the upper edge, is said to furnish 200 miner's inches. In Montana the customary method of measurement is through a vertical rectangle, one inch deep, with a head on the center of the orifice of 4 inches, and the number of miner's inches is said to be the same as the number of linear inches in the rectangle; thus under the given head an orifice one inch deep and 60 inches long would furnish 60 miner's inches. The discharge of this is said to be about 1.25 cubic feet per minute, or 75 cubic feet per hour.

The following are the values of the miner's inch in different parts of the United States. In California and Montana it is established by law that 40 miner's inches shall be the equivalent of one cubic foot per second, and in Colorado 38.4 miner's inches is the equivalent. In other States and Territories there is no legal value, but by common agreement 50 miner's inches is the equivalent of one cubic foot per second in Arizona, Idaho, Nevada, and Utah; this makes the miner's inch equal to 1.2 cubic feet per minute.

A module is an orifice which is used in selling water, and which under a constant head is to furnish a given number of miner's inches, or a given quantity per second. The size and proportions of modules vary greatly in different localities, but in all cases the important feature to be observed is that the head should be maintained nearly constant in order that the consumer may receive the amount of water for which he bargains and no more.

The simplest method of maintaining a constant head is by placing the module in a chamber which is provided with a gate that regulates the entrance of water from the main reservoir or canal. This gate is raised or lowered by an inspector once or twice a day so as to keep the surface of the water in the chamber at a given mark. This plan is a costly one, on account of the wages of the inspector, except in works where many modules are used and where a daily inspection is necessary in any event, and it is not well adapted to cases where there are frequent and considerable fluctuations in the surface of the water in the feeding canal.

Numerous methods have been devised to secure a constant head by automatic appliances; for instance, the gate which admits water into the chamber may be made to rise and fall by means of a float upon the surface; the module itself may be made to decrease in size when the water rises, and to increase when it falls, by a gate or by a tapering plug which moves in and out and whose motion is controlled by a float. These self-acting contrivances, however, are liable to get out of order, and require to be inspected more or less frequently. Another method is to have the water flow over the crest of a weir as soon as it reaches a certain height.

The use of the miner's inch, or of a module, as a standard for selling water, is awkward and confusing, and for the sake of uniformity it is greatly to be desired that water should always be bought and sold by the cubic foot per second. Only in this way can comparison readily be made, and the consumer be sure of obtaining exact value for his money.

The cut, Fig. 66, shows the form of measuring-box ordinarily used, and the following table gives the discharge in cubic feet per minute of a miner's inch of water, as measured under the various heads and different lengths and heights of apertures used in California.

Weirs

Sharp-edged Weirs. When an obstruction is placed in an open channel, so that water is caused to flow over it, it is called a dam or weir. If the top of the weir be a thin straight edge, the conditions of flow are similar to those that would exist in an orifice in a thin wall if the side contractions were suppressed and the head fell so low that the water did not fill the orifice to its top. If the portions of the dam near the walls of the channel are raised above the level of the rest so that water does not flow over them, the overflowing jet is contracted at the sides as in the case of an orifice. The general expression for the discharge of water over a weir is

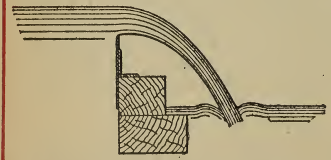


Fig. 65—SHARP-EDGED WEIR

$$Q = \tfrac{2}{3} CLH\sqrt{2gH}$$

wherein H is the height above the crest of the weir to the level of still water

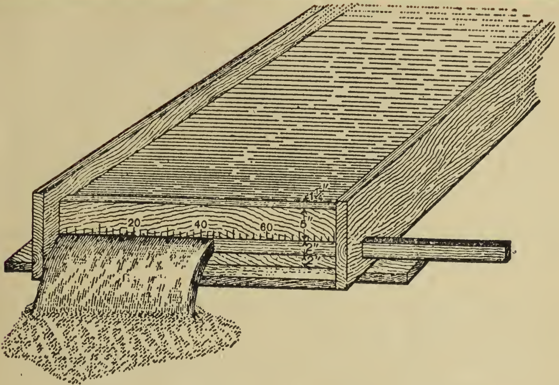


FIG. 66. MINER'S INCH MEASURING BOX

Miner's Inch Measurements

(Pelton Water Wheel Company)

Length of opening in inches	Opening 2 inches high			Opening 4 inches high		
	Head to center, 5 inches	Head to center, 6 inches	Head to center, 7 inches	Head to center, 5 inches	Head to center, 6 inches	Head to center, 7 inches
	Cubic feet	Cubic feet	Cubic feet	Cubic feet	Cubic feet	Cubic feet
4	1.348	1.473	1.589	1.320	1.450	1.570
6	1.355	1.480	1.596	1.336	1.470	1.595
8	1.359	1.484	1.600	1.344	1.481	1.608
10	1.361	1.485	1.602	1.349	1.487	1.615
12	1.363	1.487	1.604	1.352	1.491	1.620
14	1.364	1.488	1.604	1.354	1.494	1.623
16	1.365	1.489	1.605	1.356	1.496	1.626
18	1.365	1.489	1.606	1.357	1.498	1.628
20	1.365	1.490	1.606	1.359	1.499	1.630
22	1.366	1.490	1.607	1.359	1.500	1.631
24	1.366	1.490	1.607	1.360	1.501	1.632
26	1.366	1.490	1.607	1.361	1.502	1.633
28	1.367	1.491	1.607	1.361	1.503	1.634
30	1.367	1.491	1.608	1.362	1.503	1.635
40	1.367	1.492	1.608	1.363	1.505	1.637
50	1.368	1.493	1.609	1.364	1.507	1.639
60	1.368	1.493	1.609	1.365	1.508	1.640
70	1.368	1.493	1.609	1.365	1.508	1.641
80	1.368	1.493	1.609	1.366	1.509	1.641
90	1.369	1.493	1.610	1.366	1.509	1.641
100	1.369	1.494	1.610	1.366	1.509	1.642

and L is the length of the crest over which the water flows. Practically, it is not possible to measure H, but a head h may be observed to the surface of the stream above the curve of depression caused by the weir, and to this the velocity head hv due to the velocity v_a with which the water approaches the weir, may be added when the result is approximately equal to H. If the velocity of approach be small, h as observed may be treated as equal to H. C is a coefficient which depends upon the height and form of the weir, whether or not there be end contractions, the character of the weir surface and the condition of the water on the downstream side. In weir formulas it is customary to combine one or more of the factors $\frac{2}{3}$, C, and $2\,g$ into a single coefficient.

Four Recognized Formulas for the discharge of weirs are as follows, but the first and the fourth are the most important.

The Francis Formula

$$Q=3.33\ LH^{3/2} \text{ or } Q=3.33\ L\left[(h+hv)^{3/2}-hv^{3/2}\right]$$

The Fteley and Stearns Formula

$$Q=3.31\ LH^{3/2}+0.007L \text{ or } Q=3.31L(h+1.5hv)^{3/2}+0.007L$$

The Hamilton Smith Formula

$$Q=3.29(L+H/7)H^{3/2} \text{ or } Q=3.29\left(L+\frac{h+1\frac{1}{3}hv}{7}\right)(h+1\tfrac{1}{3}hv)^{3/2}$$

The Bazin Formula

$$Q=mLh\sqrt{2gh}, \text{ where } m=\left(0.405+\frac{0.00984}{h}\right)\left[1+0.55\left(\frac{h}{a+h}\right)^2\right]$$

in which a is the height of the crest of the weir above the bottom of the channel of approach. For weirs with end contractions, Francis concluded that L in the above formulas should be replaced by $L-0.1\ nH$, where n is the number of full end contractions. This correction has been generally accepted, but it is by no means accurate, and for exact work in measuring water a weir without end contractions is to be preferred. These formulas all apply to a weir with a vertical upstream face, a sharp edge and with free access of air to the under side of the overfalling sheet of water.

Triangular or V-shaped Weir. This form of weir, suggested by Prof. Thomson of Dublin, possesses the peculiarity that, whatever the heads, the sections of the stream are similar, and hence it may be expected to have a coefficient more nearly constant than the ordinary weir and be particularly well adapted to the measurement of water where the flow varies through a considerable range. The coefficient will vary for different inclinations of the sides of the notch. For a sharp-edged weir in which the sides make an angle of 90° with each other, since $L=2h$, the discharge is $Q=2.6\ h^{5/2}$.

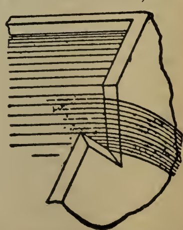


Fig. 67-Triangular Weir

No experiments have been made upon weirs of this type when other than sharp edged with vertical faces, but the effects of inclination and rounding may be expected to affect them similarly to rectangular weirs.

Rounding the Upstream Corner of the crest of a weir increases the discharge. With flat-crested weirs Bazin found this effect to amount to as much as 13% where the radius of the rounding was 4 inches and the breadth of crest 6.56 feet. Fteley and Stearns, with weirs up to one inch in breadth, found the rounding to be equivalent to increasing the head by $h_R = 0.7\ R$, where R is the radius of the rounding.

Inclining the Upstream Face away from the current decreases the contraction and increases the discharge as much as 10% when the slope is one of 45°. If the inclination be in the opposite direction, the contraction is increased and the discharge decreased. With a 45° slope, the decrease may be as much as 7%. Inclining the DOWN STREAM FACE does not materially alter the discharge until the slope becomes at least 3 horizontal to 1 vertical, when the discharge is reduced.

Rounding the Entire Crest reduces the discharge for low heads, but increases it for those wherein the curve of the crest approaches the curve of the natural under side of the sheet. By a combination of a rounded crest and an inclined upstream slope, the discharge may be increased 20% above that of the sharp-edged weir.

Flat Crests descrease the discharge until the head becomes so high that the sheet jumps clear of the downstream corner, when they have no effect. A broad flat crest may reduce the discharge 25% below that of the sharp edge.

The Sheet of Water adhering to the downstream face of a vertical sharp-edged weir has increased the discharge about 28%. The sheet being wetted, that is depressed and the space between it and the weir filled with water, due to the formation there of a partial vacuum, has increased the discharge about 15%. The sheet being depressed, but the space only partially filled with water, has increased the discharge about 6%.

Submerged Weirs. When water on the downstream side of the weir rises above the level of the crest, the weir is said to be submerged. If hu is the head observed on the upstream side and h is the difference of head on the two sides, the usual formula for the discharge of a submerged weir is

$$Q = CL\sqrt{2gh}(hu - h/3)$$

where C for a sharp edge varies from 0.58 to 0.63. On account of the difficulty of measuring hl, the head in the lower pool, because of the turbulence there, accurate results with this formula are impossible. Experiment shows that so long as the water flowing over the weir plunges to the bottom of the channel below or dives under that in the lower pool, the discharge of the weir is not decreased more than 10% by the submergence. In rounded weirs it is possible to submerge the crests to fully 30% of hu without varying the discharge from that for a free weir under the head hu more than the above percent; and for submergences of less than 10% of hu the discharge is likely to be increased by the exclusion of air behind the sheet.

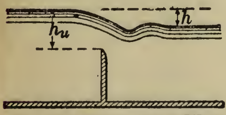


Fig. 68—Submerged Weir

FIG. 69 A LOCK-BAR PIPE LINE IN HILLY COUNTRY

The Weir affords the most commonly used method of measuring water in moderately large quantities. The standard weir, or sharp-edged weir, consists of a vertical partition across a channel with its top edge horizontal, sharp cornered and narrow enough so that at the heads used the overflowing sheet jumps from the upstream edge clear of the downstream corner. Such weirs may be either with or without end contractions. A weir with end contractions is one whose crest extends only part way across the channel and is terminated by partitions in its plane, with their vertical edges rising above the level of the water on the upstream side. Such a weir may be compared to a rectangular orifice upon which the head has fallen below the top. A weir without end contractions is one which extends entirely across the channel. If a = height of crest of weir above bottom of channel of approach, A_w = area of stream in the plane of the weir, H = height above the crest of the surface of still water upstream from the weir, h = head above crest as observed, v_w = velocity in and perpendicular to the plane of the weir, then the formula for the discharge is similar to that for the orifice and is

$$Q = A_w v_w = \tfrac{2}{3} CL \sqrt{2g}.\, H^{3/2} = \tfrac{2}{3} CL \sqrt{2g}(h+hv)^{3/2}.$$

Since $LH = L\ (h+hv)$ = area of the stream above the crest level at the plane of still water and CLH is the area in the plane of the crest, the total head producing flow is $\tfrac{2}{3}\sqrt{2g(h+hv)}$.

The Francis Formula. The coefficient C in this formula was determined experimentally by James B. Francis as about 0.62, and by combining this with, $\tfrac{2}{3}\sqrt{2g}$, the well-known coefficient of the Francis Formula 3,33 is obtained. This formula was considered by its inventor to be reliable between heads of 0.5 foot and 2.00 feet. Later investigators have modified it into the form:

$$Q = 3.33L(h+1.4hv)^{3/2}$$

In applying this formula the process is as follows: Having measured the head h at a point above the surface curve to the weir, compute an approximate value of the discharge by the equation $Q_1 = 3.33\ Lh^{3/2}$. Find the approximate velocity at the plane where the head is observed by the equation $v = Q_1 \div L(h+a)$ and the velocity head by $h = v^2/2g$. Then Q is obtained by substitution in the above formula, and should be within 3 to 4 percent of correctness if the head is not more than 30 percent of a and had been properly measured, and the sheet is fully aerated underneath.

For weirs with end contractions Francis recommended reducing the length L in the above formula by 0.1 H for each full end contraction. This correction is only an approximation and, for accurate gagings, weirs with end contractions should not be used.

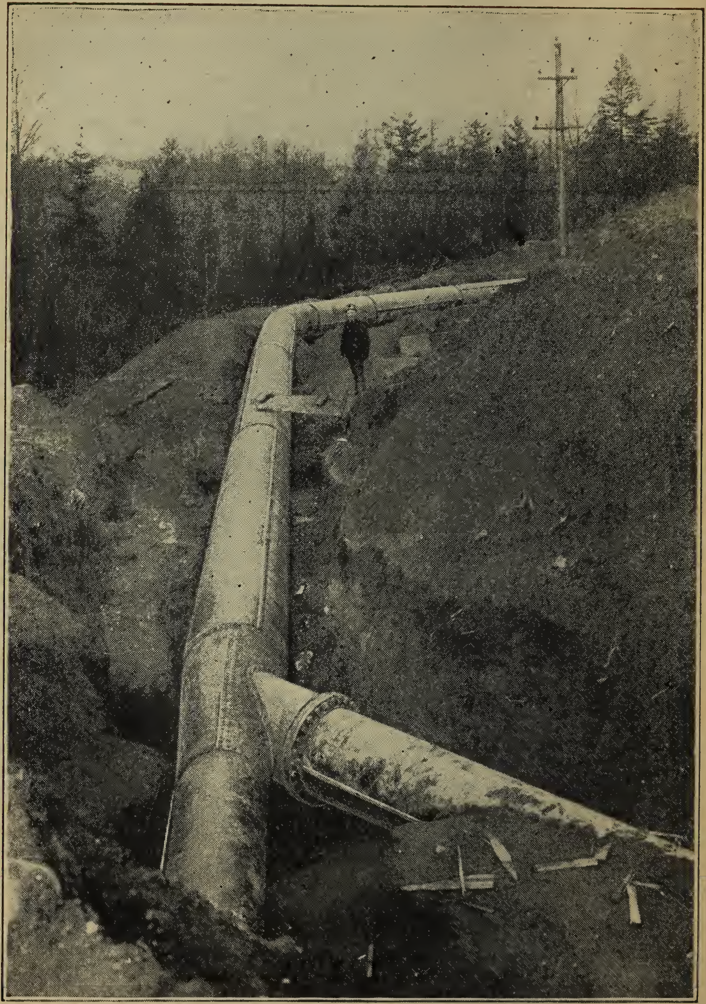


FIG. 70—A LOCK-BAR PIPE LINE SHOWING BRANCH AND CURVE

The Bazin Formula is the most accurate one for wide ranges of head, and it may be safely applied between heads of 0.2 foot and 6 feet, and does not require a correction for velocity of approach, as it is based upon the observed head h. It applies only to weirs without end contractions and is

$$Q = \left(0.405+\frac{0.00984}{h}\right)\left[1+0.55\left(\frac{h}{a+h}\right)^2\right]Lh\sqrt{2gh}$$

and the following tables give values of Q for a weir one foot long and for various values of h and a. The value of g used in computing these tables is 32.17 feet per second.

Discharge in Cubic Feet per Second per Foot of Length over Sharp-edged Vertical Weirs without End Contractions

Computed by Bazin's Formula

Head h feet	Height in feet of crest of weir above bottom of channel of approach						
	$a=2$	$a=3$	$a=4$	$a=5$	$a=6$	$a=7$	$a=8$
0.2	0.33	0.33	0.33	0.33	0.33	0.33	0.33
0.3	0.58	0.58	0.58	0.58	0.58	0.58	0.58
0.4	0.88	0.88	0.88	0.87	0.87	0.87	0.87
0.5	1.23	1.21	1.21	1.21	1.21	1.21	1.21
0.6	1.62	1.59	1.59	1.58	1.58	1.58	1.58
0.7	2.04	2.01	1.99	1.98	1.98	1.98	1.98
0.8	2.50	2.45	2.43	2.42	2.41	2.41	2.41
0.9	3.00	2.93	2.90	2.88	2.88	2.87	2.86
1.0	3.53	3.44	3.40	3.38	3.36	3.36	3.35
1.2	4.68	4.55	4.48	4.47	4.42	4.41	4.40
1.4	5.99	5.78	5.68	5.62	5.58	5.56	5.54
1.5	6.68	6.44	6.30	6.23	6.20	6.18	6.16
1.6	7.40	7.12	6.97	6.89	6.84	6.80	6.78
1.8	8.93	8.56	8.37	8.25	8.18	8.13	8.09
2.0	10.58	10.12	9.87	9.72	9.62	9.55	9.51
2.2	12.34	11.77	11.46	11.27	11.14	11.06	10.99
2.4	14.20	13.53	13.15	12.91	12.75	12.64	12.56
2.5	15.17	14.45	14.03	13.76	13.59	13.47	13.38
2.6	16.16	15.38	14.92	14.63	14.44	14.30	14.20
2.8	18.23	17.32	16.79	16.44	16.21	16.04	15.92
3.0	20.39	19.36	18.74	18.33	18.06	17.86	17.71
3.2	22.64	21.48	20.77	20.31	19.98	19.75	19.58
3.4	24.98	23.70	22.89	22.36	21.99	21.72	21.52
3.5	26.20	24.83	24.00	23.43	23.01	22.73	22.48
3.6	27.41	25.99	25.09	24.49	24.06	23.75	23.52
3.8	29.94	28.38	27.38	26.70	26.22	25.87	25.60
4.0	32.54	30.84	29.74	28.99	28.45	28.05	27.74
4.2	35.22	33.39	32.18	31.35	30.75	30.30	29.96
4.4	37.99	36.01	34.70	33.78	33.12	32.62	32.24
4.6	40.83	38.71	37.29	36.29	35.56	35.01	34.58
4.8	43.75	41.49	39.96	38.87	38.07	37.46	37.00
5.0	46.71	44.31	42.67	41.49	40.62	39.96	39.44
5.2	49.81	47.27	45.50	44.23	43.29	42.57	42.01
5.4	52.94	50.23	48.38	47.02	46.00	45.22	44.60
5.6	56.15	53.33	51.34	49.88	48.79	47.94	47.28
5.8	59.42	56.45	54.34	52.79	51.62	50.71	49.99
6.0	62.77	59.65	56.43	55.78	54.53	53.55	52.78

Discharge in Cubic Feet per Second per Foot of Length over Sharp-edged Vertical Weirs without End Contractions—Continued

Computed by Bazin's Formula

Head h, feet	Height in feet of crest of weir above bottom of channel of approach						
	$a=9$	$a=10$	$a=12$	$a=16$	$a=20$	$a=25$	$a=30$
0.2	0.33	0.33	0.33	0.33	0.33	0.33	0.33
0.3	0.58	0.58	0.58	0.58	0.58	0.58	0.58
0.4	0.87	0.87	0.87	0.87	0.87	0.87	0.87
0.5	1.21	1.21	1.21	1.21	1.20	1.20	1.20
0.6	1.57	1.57	1.57	1.57	1.57	1.57	1.57
0.7	1.97	1.97	1.97	1.97	1.97	1.97	1.97
0.8	2.40	2.40	2.40	2.40	2.40	2.40	2.40
0.9	2.86	2.86	2.86	2.86	2.85	2.85	2.85
1.0	3.35	3.34	3.34	3.33	3.33	3.33	3.33
1.2	4.39	4.38	4.38	4.37	4.36	4.36	4.36
1.4	5.53	5.52	5.51	5.49	5.49	5.48	5.48
1.5	6.14	6.13	6.12	6.11	6.10	6.09	6.09
1.6	6.76	6.74	6.73	6.71	6.69	6.69	6.69
1.8	8.07	8.05	8.02	7.99	7.98	7.97	7.96
2.0	9.47	9.44	9.40	9.36	9.34	9.33	9.32
2.2	10.95	10.91	10.86	10.81	10.78	10.76	10.75
2.4	12.50	12.45	12.39	12.32	12.28	12.25	12.24
2.5	13.31	13.26	13.18	13.10	13.06	13.03	13.01
2.6	14.13	14.07	13.99	13.90	13.85	13.82	13.80
2.8	15.83	15.76	15.66	15.54	15.48	15.44	15.42
3.0	17.60	17.52	17.39	17.25	17.18	17.13	17.10
3.2	19.45	19.34	19.19	19.02	18.93	18.87	18.83
3.4	21.36	21.24	21.06	20.86	20.75	20.68	20.63
3.5	22.38	22.22	22.00	21.83	21.69	21.62	21.60
3.6	23.34	23.20	22.99	22.75	22.62	22.53	22.48
3.8	25.39	25.23	24.99	24.71	24.56	24.45	24.39
4.0	27.51	27.32	27.05	26.72	26.55	26.42	26.35
4.2	29.69	29.48	29.17	28.79	28.59	28.45	28.36
4.4	31.94	31.70	31.34	30.92	30.66	30.52	30.42
4.6	34.25	33.98	33.58	33.10	32.84	32.65	32.53
4.8	36.62	36.33	35.88	35.35	35.05	34.83	34.70
5.0	39.03	38.70	38.21	37.61	37.28	37.03	36.88
5.2	41.56	41.20	40.65	39.99	39.61	39.33	39.17
5.4	44.11	43.71	43.12	42.38	41.96	41.66	41.47
5.6	46.74	46.31	45.65	44.84	44.38	44.04	43.83
5.8	49.41	48.94	48.22	47.33	46.83	46.45	46.22
6.0	52.15	51.64	50.86	49.90	49.34	48.92	48.67

When the weir is so high that the velocity of the approaching water is practically zero Bazin's formula reduces to

$$Q=\left(0.405+\frac{0.00984}{h}\right)Lh\sqrt{2gh}$$

At low heads, less than 0.2 of a foot, Bazin's Formula gives discharges somewhat too high and the formula proposed by Fteley and Stearns is recommended, which is:

$$Q=3.33LH^{3/2}+0.0065\,L.$$

The results by this formula are within 4 to 6 percent of the experimental values for heads ranging from 0.2 to 0.007 ft., and the actual discharges were generally in excess of those given by the formula. It holds only so long as the sheet jumps free of the crest and the space behind it is fully aerated.

The Flow over the Irregular Crests may be computed by multiplying the discharge of a standard weir of the same height and length and at the same head by a factor depending on the form of the crests. The following tables give the multipliers for various forms of weirs (Fig. 71) as determined from experiments upon full-size models at the Hydraulic Laboratory of Cornell University:

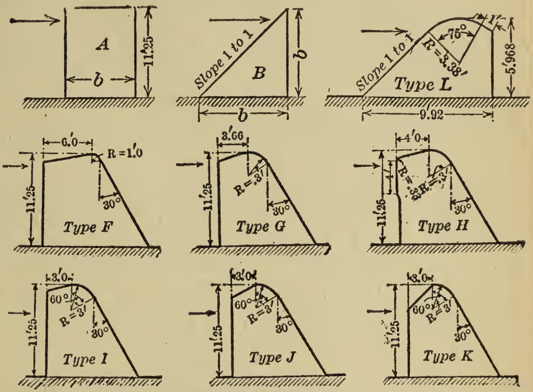


Fig. 71. Types of Weirs and Dams

Multipliers for Flat-topped Weirs. Fig. 71A

Head h, feet	Width of flat crest in feet							
	b = 0.48	b = 0.93	b = 1.65	b = 3.17	b = 5.84	b = 8.98	b = 12.24	b = 16.30
0.5	0.902	0.830	0.819	0.797	0.785	0.783	0.783	0.783
1.0	0.972	0.904	0.879	0.812	0.800	0.798	0.795	0.792
1.5	1.000	0.957	0.910	0.821	0.807	0.803	0.802	0.797
2.0	1.000	0.989	0.925	0.821	0.805	0.800	0.798	0.795
2.5	1.000	1.000	0.932	0.816	0.800	0.795	0.792	0.789
3.0	1.000	1.000	0.938	0.813	0.796	0.791	0.787	0.784
3.5	1.000	1.000	0.942	0.810	0.793	0.787	0.783	0.780
4.0	1.000	1.000	0.947	0.808	0.790	0.783	0.780	0.777

Multipliers (m) for Triangular Weirs. Fig. 71B

Head h in feet,	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
For b = 6.65 ft, m =	1.060	1.079	1.091	1.086	1.076	1.067	1.060	1.054
For b = 11.25 ft, m =	1.060	1.079	1.092	1.097	1.096	1.095	1.094	1.093

Multipliers for Compound Weirs. Fig. 71

Head h, feet	Type F	Type G	Type H	Type I	Type J	Type K	Type L
0.5	0.964	0.932	0.934	0.968	0.971	0.971	0.971
1.0	1.026	0.982	1.000	1.008	1.040	1.040	0.983
1.5	1.064	1.015	1.040	1.032	1.083	1.092	1.022
2.0	1.066	1.031	1.061	1.041	1.105	1.126	1.040
2.5	1.025	1.038	1.073	1.043	1.118	1.146	1.057
3.0	0.992	1.044	1.082	1.044	1.128	1.163	1.072
3.5	0.966	1.049	1.090	1.045	1.136	1.177	1.085
4.0	0.944	1.053	1.097	1.046	1.144	1.190	1.097

WATER POWER

(From Kent's Mechanical Engineers' Pocket Book.)

Power of a Fall of Water—Efficiency. The gross power of a fall of water is the product of the weight of water discharged in a unit of time into the total head, i. e., the difference of vertical elevation of the upper surface of the water at the points where the fall in question begins and ends. The term "head" used in connection with water-wheels is the difference in height from the surface of the water in the wheel-pit to the surface in the penstock when the wheel is running.

If Q = cubic feet of water discharged per second, D = weight of a cubic foot of water = 62.36 pounds at 60° F., H = total head in feet; then

$$DQH = \text{gross power in foot-pounds per second,}$$

and

$$DQH \div 550 = 0.1134\ QH = \text{gross horse-power.}$$

If Q' is taken in cubic feet per minute,

$$\text{H.P.} = \frac{Q'H \times 62.36}{33000} = .00189\,Q'H.$$

A water-wheel or motor of any kind cannot utilize the whole of the head H, since there are losses of head at both the entrance to and the exit from the wheel. There are also losses of energy due to friction of the water in its passage through the wheel. The ratio of the power developed by the wheel to the gross power of the fall is the efficiency of the wheel.

For 75% efficiency, net horse-power $= 0.00142\ Q'H = \dfrac{Q'H}{706}$.

A head of water can be made use of in one or other of the following ways, viz:

First. By its weight, as in the water-balance and in the overshot wheel.

Second. By its pressure, as in turbines and in the hydraulic engine, hydraulic press, crane, etc.

Third. By its impulse, as in the undershot wheel, and in the Pelton wheel.

Fourth. By a combination of the above.

Horse-power of a Running Stream. The gross horse-power is H.P. $= QH \times 62.36 \div 550 = 0.1134\ QH$, in which Q is the discharge in cubic feet per second actually impinging on the float or bucket, and

H = theoretical head due to the velocity of the stream $= \dfrac{v^2}{2g} = \dfrac{v^2}{64.4}$, in which v is the velocity in feet per second. If Q' be taken in cubic feet per minute H.P. $= 0.00189\,Q'H$.

Thus, if the floats of an undershot wheel driven by a current alone be 5 feet X 1 foot,and the velocity of stream = 210 feet per minute,or $3\frac{1}{2}$ feet per second, of which the theoretical head is 0.19 feet, $Q = 5$ square feet X 210 = 1050 cubic feet per minute; H.P. = 1050X0.19 X 0.00189 = 0.377 H.P.

The wheels would realize only about 0.4 of this power, on account of friction and slip, or 0.151 H.P., or about 0.03 H.P. per square foot of float, which is equivalent to 33 square feet of float per H. P.

Current Motors. A current motor could only utilize the whole power of a running stream if it could take all the velocity out of the water, so that it would leave the floats or buckets with no velocity at all; or in other words, it would require the backing up of the whole volume of the stream until the actual head was equivalent to the theoretical head due to the velocity of the stream. As but a small fraction of the velocity of the stream can be taken up by a current motor, its efficiency is very small. Current motors may be used to obtain small amounts of power from large streams, but for large powers they are not practicable.

Bernoulli's Theorem. Energy of Water Flowing in a Tube.

The head due to the velocity is $\frac{v^2}{2\,g}$; the head due to the pressure is $\frac{f}{w}$; the head due to actual height above the datum plane is h feet. The total head is the sum of these $= \frac{v^2}{2\,g} + h + \frac{f}{w}$, in feet, in which v = velocity in feet per second, f = pressure in pounds per square foot, w = weight of 1 cubic foot of water = 62.36 pounds. If p = pressure in pounds per square inch $\frac{f}{w} = 2.309p$. If a constant quantity of water is flowing through a tube in a given time, the velocity varying at different points on account of changes in the diameter, the energy remains constant (loss by friction excepted) and the sum of the three heads is constant, the pressure head increasing as the velocity decreases, and vice versa. This principle is known as "Bernoulli's Theorem."

In hydraulic transmission the velocity and the height above datum are usually small compared with the pressure-head. The work or energy of a given quantity of water under pressure = its volume in cubic feet X its pressure in pounds per square foot; or if Q = quantity in cubic feet per second, and p = pressure in pounds per square inch, $W = 144\ pQ$ and the H.P. $= \frac{144pQ}{550} = 0.2618\ pQ$.

Table for Calculating the Horse-power of Water Heads

(Pelton Water Wheel Company.)

The following table gives the horse-power of 1 cubic foot of water per minute under heads from 1 up to 2100 feet.

Heads in feet	Horse-power	Heads in feet	Horse-power	Heads in feet	Horse-power	Heads in feet	Horse-power
1	.0016098	220	.354156	430	.692214	1050	1.690290
20	.032196	230	.370254	440	.708312	1100	1.770780
30	.048294	240	.386352	450	.724410	1150	1.851270
40	.064392	250	.402450	460	.740508	1200	1.931760
50	.080490	260	.418548	470	.756606	1250	2.012250
60	.096588	270	.434646	480	.772704	1300	2.092740
70	.112686	280	.450744	490	.788802	1350	2.173230
80	.128784	290	.466842	500	.804900	1400	2.253720
90	.144882	300	.482940	520	.837096	1450	2.334210
100	.160980	310	.499038	540	.869292	1500	2.414700
110	.177078	320	.515136	560	.901488	1550	2.495190
120	.193176	330	.531234	580	.933684	1600	2.575680
130	.209274	340	.547332	600	.965880	1650	2.656170
140	.225372	350	.563430	650	1.046370	1700	2.736660
150	.241470	360	.579528	700	1.126860	1750	2.817150
160	.257568	370	.595626	750	1.207350	1800	2.897640
170	.273666	380	.611724	800	1.287840	1850	2.978130
180	.289764	390	.627822	850	1.368330	1900	3.058620
190	.305862	400	.643920	900	1.448820	1950	3.139110
200	.321960	410	.660018	950	1.529310	2000	3.219600
210	.338058	420	.676116	1000	1.609800	2100	3.380580

When the Exact Head is Found in Above Table

Example: Have 100-foot head and 50 cubic feet of water per minute. How many horse-power?

By reference to the above table the horse-power of each cubic foot under 100-foot head will be found to be .16098. This amount multiplied by the number of cubic feet per minute, 50, will give 8.05 horse-power.

When Exact Head is Not Found in Table

Take the horse-power of 1 cubic foot per minute under 1-foot head, and multiply by the number of cubic feet available, and then by the number of feet head. The product will be the required horse-power.

Note: The above table is based upon an efficiency of 85 per cent.

Gallons and Cubic Feet

United States Gallons in a Given Number of Cubic Feet

(1 cubic foot = 7.480519 U. S. gallons; 1 gallon = 231 cubic inches = 0.13368056 cubic foot.)

Cubic feet	Gallons	Cubic feet	Gallons	Cubic feet	Gallons
0.1	0.75	50	374.0	8 000	59 844.2
0.2	1.50	60	448.8	9 000	67 324.7
0.3	2.24	70	523.6	10 000	74 805.2
0.4	2.99	80	598.4	20 000	149 610.4
0.5	3.74	90	673.2	30 000	224 415.6
0.6	4.49	100	748.1	40 000	299 220.8
0.7	5.24	200	1 496.1	50 000	374 025.9
0.8	5.98	300	2 244.2	60 000	448 831.1
0.9	6.73	400	2 992.2	70 000	523 636.3
1	7.48	500	3 740.3	80 000	598 441.5
2	14.96	600	4 488.3	90 000	673 246.7
3	22.44	700	5 236.4	100 000	748 051.9
4	29.92	800	5 984.4	200 000	1 496 103.8
5	37.40	900	6 732.5	300 000	2 244 155.7
6	44.88	1000	7 480.5	400 000	2 992 207.6
7	52.36	2000	14 961.0	500 000	3 740 259.5
8	59.84	3000	22 441.6	600 000	4 488 311.4
9	67.32	4000	29 922.1	700 000	5 236 363.3
10	74.81	5000	37 402.6	800 000	5 984 415.2
20	149.6	6000	44 883.1	900 000	6 732 467.1
30	224.4	7000	52 363.6	1 000 000	7 480 519.0
40	299.2				

Cubic Feet in a Given Number of Gallons

Gallons	Cubic feet	Gallons	Cubic feet	Gallons	Cubic feet
1	.134	1 000	133.681	1 000 000	133 680.6
2	.267	2 000	267.361	2 000 000	267 361.1
3	.401	3 000	401.042	3 000 000	401 041.7
4	.535	4 000	534.722	4 000 000	534 722.2
5	.668	5 000	668.403	5 000 000	668 402.8
6	.802	6 000	802.083	6 000 000	802 083.4
7	.936	7 000	935.764	7 000 000	935 763.9
8	1.069	8 000	1 069.444	8 000 000	1 069 444.5
9	1.203	9 000	1 203.125	9 000 000	1 203 125.0
10	3.337	10 000	1 336.806	10 000 000	1 336 805.6

Cubic Feet per Second, Gallons in 24 Hours, etc.

Cubic feet per second.....	1/60	1	1.5472	2.2280
Cubic feet per minute.....	1	60	92.834	133.681
U. S. gallons per minute ..	7.480519	448.83	694.444	1 000
U. S. gallons per 24 hours	10 771.95	646 317	1 000 000	1 440 000
Pounds of water (at 62°F.) per minute..........	62.355	3741.3	5788.65	8335.65

Contents in Cubic Feet and United States Gallons of Pipes and Cylinders of Various Inside Diameters and One Foot in Length

(1 gallon = 231 cubic inches. 1 cubic foot = 7.4805 gallons.)

Diameter in inches	For 1 ft. in length		Diameter in Inches	For 1 ft. in length		Diameter in inches	For 1 ft. in length	
	Cubic feet, also area in square feet	U. S. gallons		Cubic feet, also area in square feet	U. S. gallons		Cubic feet, also area in square feet	U. S. gallons
¼	.0003	.0025	6¾	.2485	1.859	19	1.969	14.73
$\frac{5}{16}$	.0005	.0040	7	.2673	1.999	19½	2.074	15.51
⅜	.0008	.0057	7¼	.2867	2.145	20	2.182	16.32
$\frac{7}{16}$	.0010	.0078	7½	.3068	2.295	20½	2.292	17.15
½	.0014	.0102	7¾	.3276	2.450	21	2.405	17.99
$\frac{9}{16}$	.0017	.0129	8	.3491	2.611	21½	2.521	18.86
⅝	.0021	.0159	8¼	.3712	2.777	22	2.640	19.75
$\frac{11}{16}$	.0026	.0193	8½	.3941	2.948	22½	2.761	20.66
¾	.0031	.0230	8¾	.4176	3.125	23	2.885	21.58
$\frac{13}{16}$	.0036	.0269	9	.4418	3.305	23½	3.012	22.53
⅞	.0042	.0312	9¼	.4667	3.491	24	3.142	23.50
$\frac{15}{16}$	.0048	.0359	9½	.4922	3.682	25	3.409	25.50
1	.0055	.0408	9¾	.5185	3.879	26	3.687	27.58
1¼	.0085	.0638	10	.5454	4.080	27	3.976	29.74
1½	.0123	.0918	10¼	.5730	4.286	28	4.276	31.99
1¾	.0167	.1249	10½	.6013	4.498	29	4.587	34.31
2	.0218	.1632	10¾	.6303	4.715	30	4.909	36.72
2¼	.0276	.2066	11	.6600	4.937	31	5.241	39.21
2½	.0341	.2550	11¼	.6903	5.164	32	5.585	41.78
2¾	.0412	.3085	11½	.7213	5.396	33	5.940	44.43
3	.0491	.3672	11¾	.7530	5.633	34	6.305	47.16
3¼	.0576	.4309	12	.7854	5.875	35	6.681	49.98
3½	.0668	.4998	12½	.8522	6.375	36	7.069	52.88
3¾	.0767	.5738	13	.9218	6.895	37	7.467	55.86
4	.0873	.6528	13½	1.9940	7.436	38	7.876	58.92
4¼	.0985	.7369	14	1.069	7.997	39	8.296	62.06
4½	.1104	.8263	14½	1.147	8.578	40	8.727	65.28
4¾	.1231	.9206	15	1.227	9.180	41	9.168	68.58
5	.1364	1.020	15½	1.310	9.801	42	9.621	71.97
5¼	.1503	1.125	16	1.396	10.44	43	10.085	75.44
5½	.1650	1.234	16½	1.485	11.11	44	10.559	78.99
5¾	.1803	1.349	17	1.576	11.79	45	11.045	82.62
6	.1963	1.469	17½	1.670	12.49	46	11.541	86.33
6¼	.2131	1.594	18	1.767	13.22	47	12.048	90.13
6½	.2304	.1724	18½	1.867	13.96	48	12.566	94.00

To find the capacity of pipes greater than the largest given in the table, look in the table for a pipe of one-half the given size, and multiply its capacity by 4; or one of one-third its size, and multiply its capacity by 9, etc.

To find the weigth of water in any of the given sizes, multiply the capacity in cubic feet by 62¼ or the capacity in gallons by 8⅓, or, if a more accurate result is required, by the weight of a cubic foot of water at the actual temperature in the pipe.

Given the dimensions of a cylinder in inches, to find its capacity in U. S. gallons: Square the diameter, multiply by the length and by 0.0034. If d = diameter, l = length, gallons = $\frac{d^2 \times 0.7854 \times l}{231} = 0.0034\, d^2 l$. If D and L are in feet, gallons $= 5.875\, D^2 L$.

Cylindrical Vessels, Tanks and Cisterns

Diameter in Ft. and Ins., Area in Sq. Ft. and Capacity in U. S. Gals. for 1 Ft. in Depth

(1 gallon = 231 cubic inches = 1 cubic foot/7.4805 = 0.13368 cubic foot.)

Diameter, ft. in.	Area, square feet	Gallons, 1 foot depth	Diameter, ft. in.	Area, square feet	Gallons, 1 foot depth	Diameter, ft. in.	Area, square feet	Gallons, 1 foot depth
1 0	.785	5.87	5 8	25.22	188.66	19 0	283.53	2120.9
1 1	.922	6.89	5 9	25.97	194.25	19 3	291.04	2177.1
1 2	1.069	8.00	5 10	26.73	199.92	19 6	298.65	2234.0
1 3	1.227	9.18	5 11	27.49	205.67	19 9	306.35	2291.7
1 4	1.396	10.44	6 0	28.27	211.51	20 0	314.16	2350.1
1 5	1.576	11.79	6 3	30.68	229.50	20 3	322.06	2409.2
1 6	1.767	13.22	6 6	33.18	248.23	20 6	330.06	2469.1
1 7	1.969	14.73	6 9	35.78	267.69	20 9	338.16	2529.6
1 8	2.182	16.32	7 0	38.48	287.88	21 0	346.36	2591.0
1 9	2.405	17.99	7 3	41.28	308.81	21 3	354.66	2653.0
1 10	2.640	19.75	7 6	44.18	330.48	21 6	363.05	2715.8
1 11	2.885	21.58	7 9	47.17	352.88	21 9	371.54	2779.3
2 0	3.142	23.50	8 0	50.27	376.01	22 0	380.13	2843.6
2 1	3.409	25.50	8 3	53.46	399.88	22 3	388.82	2908.6
2 2	3.687	27.58	8 6	56.75	424.48	22 6	397.61	2974.3
2 3	3.976	29.74	8 9	60.13	449.82	22 9	406.49	3040.8
2 4	4.276	31.99	9 0	63.62	475.89	23 0	415.48	3108.0
2 5	4.587	34.31	9 3	67.20	502.70	23 3	424.56	3175.9
2 6	4.909	36.72	9 6	70.88	530.24	23 6	433.74	3244.6
2 7	5.241	39.21	9 9	74.66	558.51	23 9	443.01	3314.0
2 8	5.585	41.78	10 0	78.54	587.52	24 0	452.39	3384.1
2 9	5.940	44.43	10 3	82.52	617.26	24 3	461.86	3455.0
2 10	6.305	47.16	10 6	86.59	647.74	24 6	471.44	3526.6
2 11	6.681	49.98	10 9	90.76	678.95	24 9	481.11	3598.9
3 0	7.069	52.88	11 0	95.03	710.90	25 0	490.87	3672.0
3 1	7.467	55.86	11 3	99.40	743.58	25 3	500.74	3745.8
3 2	7.876	58.92	11 6	103.87	776.99	25 6	510.71	3820.3
3 3	8.296	62.06	11 9	108.43	811.14	25 9	520.77	3895.6
3 4	8.727	65.28	12 0	113.10	846.03	26 0	530.93	3971.6
3 5	9.168	68.58	12 3	117.86	881.65	26 3	541.19	4048.4
3 6	9.621	71.97	12 6	122.72	918.00	26 6	551.55	4125.9
3 7	10.085	75.44	12 9	127.68	955.09	26 9	562.00	4204.1
3 8	10.559	78.99	13 0	132.73	992.91	27 0	572.56	4283.0
3 9	11.045	82.62	13 3	137.89	1031.5	27 3	583.21	4362.7
3 10	11.541	86.33	13 6	143.14	1070.8	27 6	593.96	4443.1
3 11	12.048	90.13	13 9	148.49	1110.8	27 9	604.81	4524.3
4 0	12.566	94.00	14 0	153.94	1151.5	28 0	615.75	4606.2
4 1	13.095	97.96	14 3	159.48	1193.0	28 3	626.80	4688.8
4 2	13.635	102.00	14 6	165.13	1235.3	28 6	637.94	4772.1
4 3	14.186	106.12	14 9	170.87	1278.2	28 9	649.18	4856.2
4 4	14.748	110.32	15 0	176.71	1321.9	29 0	660.52	4941.0
4 5	15.321	114.61	15 3	182.65	1366.4	29 3	671.96	5026.6
4 6	15.90	118.97	15 6	188.69	1411.5	29 6	683.49	5112.9
4 7	16.50	123.42	15 9	194.83	1457.4	29 9	695.13	5199.9
4 8	17.10	127.95	16 0	201.06	1504.1	30 0	706.86	5287.7
4 9	17.72	132.56	16 3	207.39	1551.4	30 3	718.69	5376.2
4 10	18.35	137.25	16 6	213.82	1599.5	30 6	730.62	5465.4
4 11	18.99	142.02	16 9	220.35	1648.4	30 9	742.64	5555.4
5 0	19.63	146.88	17 0	226.98	1697.9	31 0	754.77	5646.1
5 1	20.29	151.82	17 3	233.71	1748.2	31 3	766.99	5737.5
5 2	20.97	156.83	17 6	240.53	1799.3	31 6	779.31	5829.7
5 3	21.65	161.93	17 9	247.45	1851.1	31 9	791.73	5922.6
5 4	22.34	167.12	18 0	254.47	1903.6	32 0	804.25	6016.2
5 5	23.04	172.38	18 3	261.59	1956.8	32 3	816.86	6110.6
5 6	23.76	177.72	18 6	268.80	2010.8	32 6	829.58	6205.7
5 7	24.48	183.15	18 9	276.12	2065.5	32 9	842.39	6301.5

Number of Barrels (31½ Gallons) in Cylindrical Cisterns and Tanks

(1 barrel = 31½ gallons = 31.5 × 231/1728 = 4.21094 cu. ft.; reciprocal = 0.237477.)

Depth in feet	Diameter in feet 5	6	7	8	9	10	11	12	13
1	4.663	6.714	9.139	11.937	15.108	18.652	22.569	26.859	31.522
5	23.3	33.6	45.7	59.7	75.5	93.3	112.8	134.3	157.6
6	28.0	40.3	54.8	71.6	90.6	111.9	135.4	161.2	189.1
7	32.6	47.0	64.0	83.6	105.8	130.6	158.0	188.0	220.7
8	37.3	53.7	73.1	95.5	120.9	149.2	180.6	214.9	252.2
9	42.0	60.4	82.3	107.4	136.0	167.9	203.1	241.7	283.7
10	46.6	67.1	91.4	119.4	151.1	186.5	225.7	268.6	315.2
11	51.3	73.9	100.5	131.3	166.2	205.2	248.3	295.4	346.7
12	56.0	80.6	109.7	143.2	181.3	223.8	270.8	322.3	378.3
13	60.6	87.3	118.8	155.2	196.4	242.5	293.4	349.2	409.8
14	65.3	94.0	127.9	167.1	211.5	261.1	316.0	376.0	441.3
15	69.9	100.7	137.1	179.1	226.6	279.8	338.5	402.9	472.8
16	74.6	107.4	146.2	191.0	241.7	298.4	361.1	429.7	504.4
17	79.3	114.1	155.4	202.9	256.8	317.1	383.7	456.6	535.9
18	83.9	120.9	164.5	214.9	271.9	335.7	406.2	483.5	567.4
19	88.6	127.6	173.6	226.8	287.1	354.4	428.8	510.3	598.9
20	93.3	134.3	182.8	238.7	302.2	373.0	451.4	537.2	630.4

Depth in feet	14	15	16	17	18	19	20	21	22
1	36.557	41.966	47.748	53.903	60.431	67.332	74.606	82.253	90.273
5	182.8	209.8	238.7	269.5	302.2	336.7	373.0	411.3	451.4
6	219.3	251.8	286.5	323.4	362.6	404.0	447.6	493.5	541.6
7	255.9	293.8	334.2	377.3	423.0	471.3	522.2	575.8	631.9
8	292.5	335.7	382.0	431.2	483.4	538.7	596.8	658.0	722.2
9	329.0	377.7	429.7	485.1	543.9	606.0	671.5	740.3	812.5
10	365.6	419.7	477.5	539.0	604.3	673.3	746.1	822.5	902.7
11	402.1	461.6	525.2	592.9	664.7	740.7	820.7	904.8	993.0
12	438.7	503.6	573.0	646.8	725.2	808.0	895.3	987.0	1083.3
13	475.2	545.6	620.7	700.7	785.6	875.3	969.9	1069.3	1173.5
14	511.8	587.5	668.5	754.6	846.0	942.6	1044.5	1151.5	1263.8
15	548.4	629.5	716.2	808.5	906.5	1010.0	1119.1	1233.8	1354.1
16	584.9	671.5	764.0	862.4	966.9	1077.3	1193.7	1316.0	1444.4
17	621.5	713.4	811.7	916.4	1027.3	1144.6	1268.3	1398.3	1534.5
18	658.0	755.4	859.5	970.3	1087.8	1212.0	1342.9	1480.6	1624.9
19	694.6	797.4	907.2	1024.2	1148.2	1279.3	1417.5	1562.8	1715.2
20	731.1	839.3	955.0	1078.1	1208.6	1346.6	1492.1	1645.1	1805.5

Depth in feet	23	24	25	26	27	28	29	30
1	98.666	107.432	116.571	126.083	135.968	146.226	156.858	167.863
5	493.3	537.2	582.9	630.4	679.8	731.1	784.3	839.3
6	592.0	644.6	699.4	756.5	815.8	877.4	941.1	1007.2
7	690.7	752.0	816.0	882.6	951.8	1023.6	1098.0	1175.0
8	789.3	859.5	932.6	1008.7	1087.7	1169.8	1254.9	1342.9
9	888.0	966.9	1049.1	1134.7	1223.7	1316.0	1411.7	1510.8
10	986.7	1074.3	1165.7	1260.8	1359.7	1462.2	1568.6	1678.6
11	1085.3	1181.8	1282.3	1386.9	1495.6	1608.5	1725.4	1846.5
12	1184.0	1289.2	1398.8	1513.0	1631.6	1754.7	1882.3	2014.4
13	1282.7	1396.6	1515.4	1639.1	1767.6	1900.9	2039.2	2182.2
14	1381.3	1504.0	1632.0	1765.2	1903.6	2047.2	2196.0	2350.1
15	1480.0	1611.5	1748.6	1891.2	2039.5	2193.4	2352.9	2517.9
16	1578.7	1718.9	1865.1	2017.3	2175.5	2339.6	2509.7	2685.8
17	1677.3	1826.3	1981.7	2143.4	2311.5	2485.8	2666.6	2853.7
18	1776.0	1933.8	2098.3	2269.5	2447.4	2632.0	2823.4	3021.5
19	1874.7	2041.2	2214.8	2395.6	2583.4	2778.3	2980.3	3189.4
20	1973.3	2148.6	2321.4	2521.7	2719.4	2924.5	3137.2	3357.3

SOURCE

A Waterworks System must secure its supply when and where it can be gotten, and must deliver it when and where required by its customers, or "takers." Waterworks structures are required to collect the water; to hold it from times when it is available until it is required; to pump it to a higher elevation; to convey it from the point where it is available to the points where it is required, and to allow the water to be measured and controlled at all points. Water is required by the takers at very unequal rates, following the requirements and emergencies that arise in their business, and the fundamental requirement controlling the design of works is to secure the ability to supply water wherever and whenever required and in whatever reasonable amounts may be needed.

COLLECTION OF WATER

Intakes

Intakes are structures built out into a body of water for the purpose of drawing water for use. The position of intakes is often affected by considerations of local pollution when sewage is allowed to flow into the same body of water from which the supply is taken. This is commonly the case in cities located upon rivers and great lakes. The depth of intake is frequently a matter of importance where water of different qualities is to be obtained at different levels. There are three types of intakes: (1) Unprotected intakes, (2) Submerged intakes, (3) Exposed or tower cribs.

Unprotected intakes are used for small supplies. The pipe is allowed to terminate at the desired point, sometimes being protected by a coarse screen. A fine screen is not permissible because it will be clogged by matters carried by the water.

A submerged Crib is a structure built on the bottom of the lake or river from the interior of which the water is taken. It serves the purpose of roughly screening the water and also of protecting the end of the intake pipe from damage. Exposed or TOWER CRIBS are structures built on the bottom of the river or lake and extending above high water. They are frequently provided at different levels with ports controlled by gates, and screens may be located in their interiors. Tower cribs have many advantages for large supplies. The ports may be closed and the water pumped out of the intake pipe and everything inspected for tightness and condition. Screens in them may be reached for cleaning and repairs. Tower cribs require excellent foundations and they must be built strong enough to withstand ice pressures. In cold climates they are only used for large supplies. In warmer climates where ice pressure is not effective they are also used for small supplies.

Intake pipes or conduits are the connecting channels between the intakes and the shore.

Steel Pipes for intakes are laid in much the same way as cast-iron pipes. Flexible joints are riveted to the ends of the steel pipes where required (Fig. 72), but the length of steel pipe between such joints may be greater, as steel pipe is stronger and more rigid than cast-iron pipe. Steel pipe is frequently designed to fit closely the contour of the bottom and it can then be put together with ordinary flange joints bolted up by a diver.

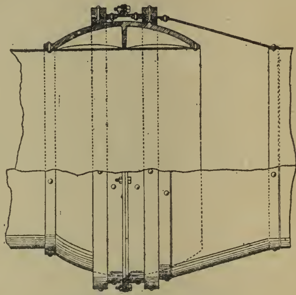


Fig. 72-Flexible Joint

Depth of Cover for Steel Pipe must not be excessive or the weight of the earth will flatten and deform it. A slight flattening is **not** objectionable as it does not cause the pipe to leak and does not greatly reduce its carrying capacity.

In bad trenches and where material is slippery the depth of cover should be kept somewhat less than in solid ground. With firm material carefully placed around the pipe and well rammed on the sides the depth of cover for short distances may be greater than in loose caving material. If it is necessary to cover thin pipe to a great depth it may be stiffened by angle irons riveted to it at frequent intervals. A more substantial result is obtained by surrounding the pipe with concrete.

USEFUL INFORMATION.

Cubic yards of earth in ditches with side slopes of one foot in ten.

Bottom Width	DEPTH IN FEET											
	4	5	6	7	8	9	10	12	14	16	18	20
2 ft......	.36	0.48	0.60	0.72	0.86	0.99	1.15	1.46	1.80	2.19	2.59	2.96
2½ ft......	.44	0.57	0.71	0.85	1.01	1.16	1.33	1.68	2.06	2.48	2.92	3.33
3 ft......	.51	0.66	0.82	0.98	1.16	1.33	1.51	1.90	2.32	2.80	3.25	3.70
3½ ft......	.65	0.76	0.93	1.11	1.30	1.49	1.70	2.12	2.58	3.10	3.58	4.07
4 ft......	.66	0.84	1.04	1.24	1.45	1.66	1.88	2.34	2.84	3.40	3.91	4.44
4½ ft......	.74	0.94	1.15	1.37	1.60	1.83	2.07	2.57	3.10	3.70	4.24	4.81
5 ft......	.81	1·04	1.26	1.50	1.75	2.00	2.25	2.80	3.36	4.00	4.57	5.18

Gates on Steel Pipes. There are two ways of connecting gates in steel pipes: (1) By flange connections, the flanges being riveted to the steel pipe and bolted to flange gates. The gates must have cases heavy enough and strong enough to withstand the temperature stresses in the steel pipe. This is essential. If flange gates of ordinary construction are used the cases are sure to be broken by the expansion and contraction of the pipe. (2) The

gates may be connected with the steel pipe through short pieces of cast-iron pipe and lead joints. In this case it is necessary to build anchorages on the steel pipe on either side of the gates. The two anchorages having equal and opposite temperature strains to hold may be conveniently connected by old steel rails laid in concrete.

Connections and Accessories of Gates. Gates are furnished with either flange or bell ends at about the same cost. Bell ends are generally used in pipe lines in street work; flange connections are used in gatehouses, pumping stations, and about filter plants. GATE BOXES are metallic boxes covering the wrench connection and gate, extending to the surface of the ground, with an expansion joint to protect them from damage by frost and traffic and with a removable cover to allow the gate to be opened from the surface with a suitable wrench after removing the cover.

Manholes of masonry are often built about gates of special importance, large gates, and gates operated by gears, especially when located under pavements or in other places not easily accessible. It is not necessary to build such manholes about small gates because such gates can be readily and cheaply dug up in the infrequent cases of access to them being necessary.

Gears are used on large gates and gates under heavy pressure. In general 36-inch gates, 10 lb per sq. in. working pressure; 30-inch gates, 50 lb. per sq. in working pressure; and 20-inch gates, 150 lb. per sq. in.working pressure, are the smallest gates to be geared. SPUR GEARS are used on gates set vertically and opening upward, and BEVELED GEARS on gates set horizontally and opening sideways. The latter are to be used wherever the vertical space is not sufficient to put in the spur-geared gates.

By-passes are provided in many cases on large gates operating under heavy pressures. These are built into and form part of the main gate. A small gate on the by-pass is opened to equalize the pressures in the pipe on either side of the gate before the main gate is opened. This allows the main gate to be opened with less effort than would otherwise be required.

Hydraulically Operated Gates in which the screws of the ordinary gate are omitted, have hydraulic cylinders provided with plungers attached directly to the moving parts. A small control valve allows high-pressure water to act on one side of the other of the plunger, opening and closing the gate. The cost is about twice that of ordinary gates.

Hydraulically operated gates with "rising screw" stems were first installed at Rochester, N. Y., at Cobbs Hill Reservoir. Surmounting the operating cylinder is a yoke upon which there is an adjustable clutch which engages the screw stem and allows the gate to be operated by hand cranks, whenever there is insufficient pressure in the Conduit for hydraulic operation.

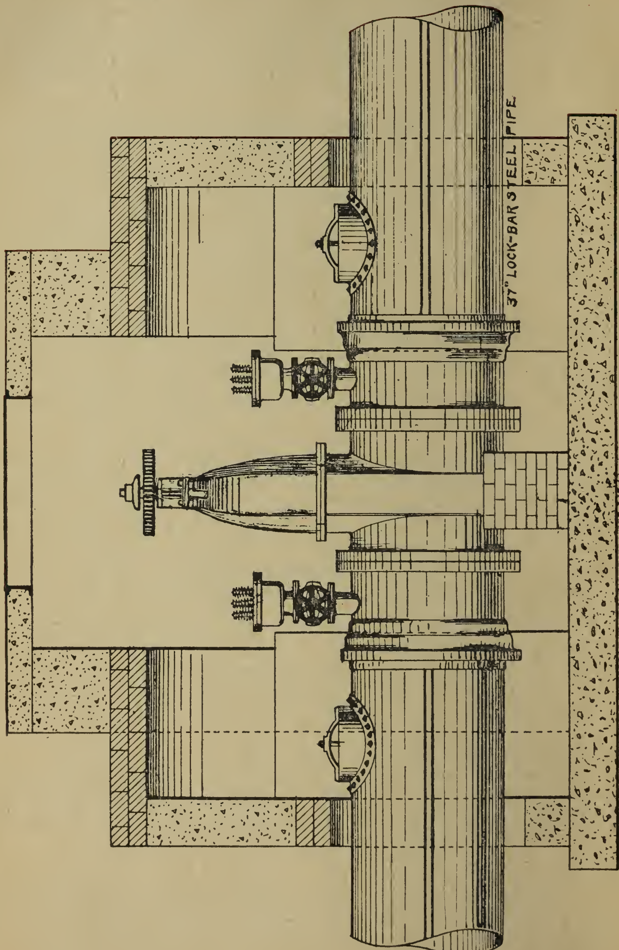


Fig. 73—TYPICAL VAULT FOR GATE VALVE INSTALLATION

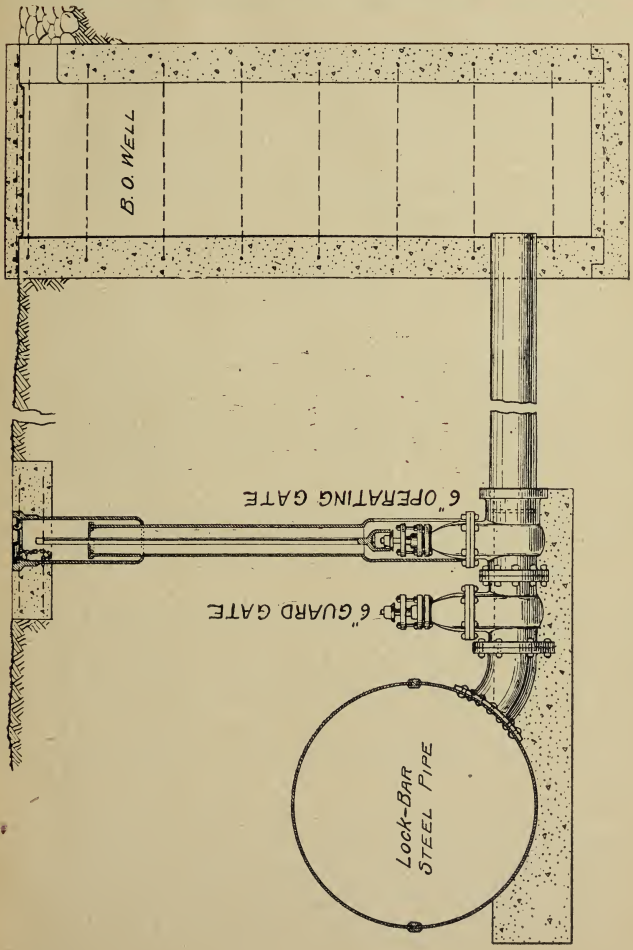


Fig. 74—TYPICAL BLOW-OFF VALVE INSTALLATION

Gates should not be placed where they cannot be inspected and tested and kept in good order.

Electrically Operated Gates are furnished with electric motors geared to the screws that open and close them. Such gates are used occasionally in pumping stations and about filters where electric current is available.

Sluice Gates are of simpler construction, arranged for being built into masonry of reservoirs and other structures, and for holding water against moderate heads only. There is great variety in the design of sluice gates. They are usually cheaper than standard gates, and for the services to which they are adapted are fully satisfactory.

Auxiliaries

Air Valves are small valves attached to pipes for the purpose of automatically letting out air. They are placed on summits only. Automatic air valves need only to be placed on summits of cast-iron pipe lines where the pressure is light and variable, that is, on summits nearly up to the hydraulic grade line. On all summits where the water is under considerable pressure it is sufficient to put on a petcock or a larger valve to be opened while the pipe is being filled and which can be closed at all other times. As air is more soluble in water under pressure there is no danger of the separation of air at summits under considerable pressure, and should air be accidentally introduced to them it would be slowly dissolved and removed by the passing water. As a general rule air valves with a diameter of one inch for each foot in diameter of the water pipe are sufficient. The air valves must be protected from frost by specially constructed boxes to insure their being in readiness to act in winter.

For Steel Pipe air valves are also required to let air into the pipe rapidly in case of need, as the pipe is not so constituted that it will support itself against outside pressure with a vacuum in the inside. A break in a pipe at a low point, allowing the water to run out rapidly, would cause a vacuum in higher parts of the pipe, which would cause the pipe to collapse. Consideration of this feature has led to placing air valves for automatically admitting air on summits of steel pipe. Generally the air valve for this purpose should have a net area equal to a circle one-eighth of the diameter of the pipe.

Air valves are to be insisted upon in all steel-pipe lines, but it must be remembered that they are called upon to act very rarely indeed, and for this reason a defective valve or arrangement may be used without the discovery being made that it is defective, and the fact that a simpler or cheaper type of air valve has been used in certain cases where there have been no breaks and consequently no demand that has taxed its capacity is not to be taken as an indication of the sufficiency of that particular design.

Blow-offs are small pipes attached at low points for the purpose of drawing off and wasting the water, contained in the pipe during times of inspection and repair. Blow-offs are usually much smaller in diameter than the main pipe. The necessity of blow-offs depends upon the character of the water and the service of the pipe.

In general an air valve is placed on each summit and a blow-off at the bottom of each, sag in a pipe conduit line. They are generally unnecessary or very infrequent in distribution mains as there are so many connections, fire hydrants etc., which may be utilized.

Manholes consisting of saddles attached to the pipe and removable covers capable of being bolted securely to the frame are placed on steel pipes at distances ranging from 1000 to 2000 feet apart, to allow the pipe to be entered during construction and afterward for inspection and repair. In some cases manholes have been placed on cast-iron pipes, altho most lines have been built without them.

Twin Lines of pipe are used in places of special danger. Either line will maintain at least a partial supply in case of break in the other. In case twin lines are long, there should be cross connections with gates so that in case of a break in either line a section only can be cut out, the flow at other points continuing through both lines. With this arrangement, the amount of water flowing through the system will be more than would flow through one line only.

The Cost of Twin Lines with cross connections is from 30 to 50 percent greater than the cost of a single line of pipe of the same strength and capacity. Where no other purpose than safety is secured by dividing the flow, it is generally better to spend the added money, or a part of it, in strengthening one line and making it secure beyond question rather than dividing it between two smaller lines. River crossings, lines over coal fields, where there are sure to be settlements, and other points of special hazard are best crossed with twin lines. THREE LINES of pipe cost from 60 to 80 percent more than one line of equal strength and capacity.

Water Supply Conduits

Leakage should be avoided as far as possible. All visible leaks should be stopped and the pipe examined in open trench under test pressure.

Sand Cutting sometimes occurs where leaks occur in sharp sandy soil. A small jet from an imperfect lead joint has been known to wash sand in such a way as to cut entirely through the band of the pipe.

Tubercles in Cast-iron Pipe. The carrying capacity of cast-iron pipe is reduced in course of time by the growth of tubercles upon the interior of

the pipe. In a general way the capacity of the pipe, other things being equal, is reduced from this cause by as much as one percent per annum. In small pipes the deterioration is more rapid. Generally the deterioration is less rapid with clear lake waters and more rapid with turbid river waters, and especially waters carrying organic matter. Filtered river waters act more nearly like lake waters.

Tubercles can be Removed by sending an instrument driven by the water pressure through the pipe. This instrument is called a "go-devil." Scraping off the tubercles in this way increases the carrying capacity of the pipe. After the pipe has been scraped tubercles grow more rapidly than before, so that the remedy is a temporary and not a permanent one. When the pipe is once scraped it is usually necessary to scrape it again, and the process becomes an annual one, or the period may be even shorter.

Organisms. A well coated steel plate pipe has a smooth surface upon which organisms do not adhere as readily as to the rougher surface of cast-iron pipes.

These growths increase during warm weather and fall off to some extent as the water gets colder in the winter.

Spring gaugings of long pipe lines which have been in use for some time show somewhat greater discharge than when the same conduits are gauged in the autumn.

Effect of Cleaning upon the Quality of the Water. The corrosion and tuberculation of iron pipes always adds iron to the water, and this iron gives it a color, tends to deposit and is objectionable. Scraping the pipes frequently increases the rate of tuberculation and increases whatever objection there may be to the iron in the water from this source.

Pressure for Domestic Service Only. At the street line 20 lb. per sq. in. will raise water to the upper floor of three-story residences and allow a fair service, but generally 40 lb. per sq. in. is the least allowance for fair domestic service. For business blocks and higher buildings higher pressures are needed; 60 or 70 lb. per sq. in. is not too much to give fair service in mills and business blocks that are not especially high. High steel buildings generally pump their own water and no effort is made to supply them without such pumping.

Pressure for Fire Service. If steam fire engines are used and depended upon as in many American cities, the only requirement for pressure is that during fires and with the heaviest draft the pipes shall have sufficient capacity to supply water to the steam fire engines and at the same time retain as much pressure as is needed for domestic service. If the pressure is higher, hose streams can be obtained from the hydrants without the use of the fire engines. The additional pressure to permit this to be done is very desirable. 70 lbs. during fires is the lowest pressure that permits effective hose streams

to be obtained for use on buildings of moderate size. If only residences are involved, 50 or 60 lbs. will give fair streams. In business districts with large buildings better hose streams are obtained with higher pressures, and in general the higher the pressure the better the fire service. 100 lbs. gives a good working service without steam fire engines. Higher pressures up to 150 lbs. and more are available in many cities.

Reservoirs and Standpipes

Distributing Reservoirs are connected immediately with the distribution system and as near as possible to the center of population supplied. Their function is to take water when it comes and to make it available when it is needed. They are especially to maintain the service at times of fire and on other occasions when water is drawn rapidly. Frequently they also serve the purpose of allowing the pumps supplying the service to be shut down during certain hours of the day or at night, thereby economizing labor. This is especially the case in small plants. OPEN RESERVOIRS with earth embankments or masonry walls have been frequently used and are most economical for the storage of large quantities of surface or lake waters. Ground waters and filtered waters always deteriorate in quality in such reservoirs, owing to the growth of certain organisms in the sunlight. COVERED RESERVOIRS are always to be preferred for such waters. Roofs are sometimes used to exclude the light and keep the water from deteriorating. A light roof not necessarily water-tight serves this purpose.

Masonry Covers for distributing reservoirs are often used. At Washington, D. C., Springfield, Mass., and elsewhere, groined arch construction has been used. Floors to carry the weight of the roof and distribute it over the whole base are built as inverted groined arches. The piers are of concrete, as thick as 12% of the span on centers, and not more than 12 times as high as thick. If the reservoir is deep, large piers will be required to meet this condition, and the span of the arches is increased to correspond. The roof is of groined arch vaulting without reinforcing. The outside walls, with a minimum thickness of about 12% of their height at top and 16% at bottom, are braced at the bottom by the floor blocks and at the top by the roof blocks, and are calculated as reinforced beams, with breaking moment at about 43% of the distance from the bottom to the top, equal to $4h^3$, being the height of the wall in feet. In deep reservoirs economy is secured by carrying the floor on a slope of about 1 in 6 to the raised base of the walls, thereby reducing the height of the walls. The masonry is backed up by solid earth embankment, and two feet of soil is placed over the top to keep frost from the masonry. Ventilators are provided to allow the passage of air as water rises and falls in the reservoir. The top is covered with grass and shrubbery, but trees or any plants with strong heavy roots should not be planted.

PIPE LINE TESTING.

Special precautions should be taken before placing hydraulic pressure tests on a steel pipe line after the same has been laid in a trench, prior to placing line in service.

1. See that all pipe line centers are properly backfilled and the line is thus weighted down to prevent floating.

2. All test heads or gate valves should be securely braced.

3. All blow-off valves should be closed.

4. All automatic air valves should be in position and in proper working order, with the control gate valves wide open.

5. No section of pipe should be tested without having at least one automatic air valve installed and in proper working order, even though the same may not be required for permanent operation.

INSTALLATION OF LARGE STEEL PIPES

Transportation

Pipe is unloaded from the cars by any convenient equipment such as a locomotive crane, derrick, yard gantry or other apparatus or it can be unloaded by hand by snubbing it with a preventer line and rolling it down inclined skids or it can be hauled or lowered by the aid of teams.

Distribution along the pipe line is governed largely by the topography of the country, the length of the line, the size of the pipe and the facilities convenient. For a large amount of heavy pipe in a tolerably level country it pays to construct a narrow gage service track and haul the pipe with dinky locomotives.

For short lines or very light pipe delivery can be made by automobile trucks or trucks and trailers or the pipe can be loaded directly on timber sleds or on pole wagons according to topographical and weather conditions. It is distributed close to the line of the trench and securely blocked to prevent it from rolling down hill. Generally it is more convenient to handle when laid parallel with the trench but when the topography does not permit this arrangement it may be placed at a skew or at right angles to the axis of the trench. In any case it can be slewed, rolled or snubbed into position for finally lowering into the trench, due care being given to protection of the coating.

Trench Excavation

The trench is usually made with a clear width of 12 to 18 in. more than the diameter of the pipe and deep enough to provide at least 2 ft. of cover over the top of the pipe. This amount of earth is considered necessary for adequate protection from loads and impact exclusive of protection required from frost.

In very rough or stony country it may be necessary to make the excavation by hand or with scrapers and teams, but the latter method necessitates sloping banks. In shale, hardpan or rock, drilling with compressed air machines and blasting are generally necessary although soft or rotten rock and hard strata may sometimes be excavated by steam shovels without blasting.

When the amount of work, character of the soil and the topography permit, it is generally more rapid and economical to excavate with a trench machine or a light revolving steam shovel with a long boom and bucket.

When the revolving steam shovel is used, it travels over the excavated trench supported on timber mats spanning the trench that are taken up in the rear and laid down in advance by the shovel itself as it progresses. The use of the steam shovel for excavation is of advantage in that it permits the separation of the spoil into waste and into suitable backfilling material.

In order to accommodate or rivet and caulk the transverse field joints 30 ft. apart, bell holes 4 ft. long and 1 ft. deep are dug at the bottom of the trench and between then the bottom is carefully levelled to uniform grade to support the pipe continuously.

Lowering and Assembling

The pipe trench is spanned by transverse wooden skids on which the pipe is rolled in a position directly above the centre line of the trench and with the rear end of the section just over the forward end of the last assembled section. One or two stiffleg derricks are set opposite the pipe section on the side of the trench or a pair of tripods with hand crabs operating manilla tackles are set up over the pipe, one near each end, manilla rope slings are placed around the pipe and engage the tackles, the pipe is hoisted slightly, skids removed, and the pipe lowered to approximate position on the bottom of the trench.

When the pipe is intended for riveted transverse circular field joints, the rear end of the last section is entered in the forward end of the preceding section by means of steel spud bars flattened on one end and pointed on the other end. The flat end is used as a wedge for entering the pipe and the pointed end as a drift to engage the open rivet holes and pull them to registration. The bars are made a few inches shorter than the pipe diameter so that they may have clearance for operation inside the pipe. When the rivet holes register they are service bolted and matched with a few additional drift pins to prevent the possibility of displacement by creeping, expansion or contraction or by disturbances in assembling the next section. When necessary the entrance of one pipe into the next may be promoted by a longitudinal pull and hoist with the derrick.

For a pipe of medium size, say 40 in. in diameter, the normal pipe laying gang consists of about 25 to 35 men who roll the pipe on the skids, bring up and set the derricks, enter the pipe sections, and bolt up the joints.

With field riveted joints, vertical and horizontal angles up to a deflection of three degrees can be made with standard sections entered in tangent alignment and then forced into transverse positions corresponding to the spacing of the rivet holes carefully located to conform with the required deflection.

Riveting

The five-man riveting gang removes the temporary joint bolts, lays up the steel plate tightly with an iron maul, and bolts the pipe securely with sufficient bolts to hold the sheets tight for reaming and riveting. Riveting is usually done by pneumatic tools, operated on the outside except for the bottom half of the circumference where riveting is usually done from the inside.

Rivets are heated in hand blast coal furnaces on the surface of the ground adjacent to the pipe joints and are delivered to the interior of the pipe through drop holes up to 2 in. in diameter that are provided for that purpose on the upper side of the pipe at every joint and are afterwards closed with screw plugs.

On long lines or where the work is subject to delay or interruption at special points, the pipe is assembled sometimes in sections commenced at different points and eventually joined to each other by special closures. After the joints are riveted they are painted with a special preservative paint. Extended use is made of the patented high pressure flexible couplings for transverse field joints with lock-bar pipe for gas lines and on diameters of 24″ and on under water lines where the pipe is too small to permit working on the inside.

After the field joints are completed the pipe is tested in convenient lengths of from 1 to 4 miles by pneumatic pressure for gas mains and in lengths of from ½ to 2 miles by hydraulic pressure for water mains to a required pressure, usually 50% in excess of the normal working pressure contemplated.

Elevated and Submerged Pipes

When it is desirable to elevate pipe concrete piers spaced about 30 ft. apart are generally used. On short trestles the pipe sections may often be most advantageously distributed on the surface of the ground and successively lifted to position by derricks or locomotive cranes.

On long trestles it is generally desirable to provide a service track alongside for the delivery of the pipes. Usually one of the track stringers is laid directly on the pier tops alongside of the pipe and the opposite stringer is supported on a single vertical falsework post braced to the concrete pier. The saddle tops of the piers are spanned by skids on which the pipes are delivered. Afterwards the pipes are raised, skids removed and the pipes lowered to position on the piers where they are assembled and riveted in the same manner as in trenches.

Submerged pipe is always laid in a protecting trench which when the conditions will permit, is generally most advantageously excavated by a hydraulic dredge. If the bottom is of rock or hard strata the excavation is usually done with a dipper dredge. Submerged pipe should be provided with flexible joints and can generally be floated to the site in 100 or 150 ft. lengths closed with temporary bulkheads. They are sunk to the bottom by admitting water and the successive sections are connected up by divers making the bolted joints. Sometimes the pipes are sunk between guide piles and sometimes special equipment for floating, sinking and connecting them is devised and installed to correspond with conditions and requirements.

Submerged pipe trenches are usually backfilled to a depth of about 2 ft. and when they are exposed to wave action, the covering is protected by rip rap.

Fig. 75—LOCK-BAR PIPE LINE. SHOWING CLOSING IN PIECE.

Data for Steel Standpipes

Dia. in feet	Height in feet	Capacity in thousand gallons	Required thickness of lowest plate with stress not exceeding 10 000 lbs, in	Thickness of bottom, inches	Approximate weight in net tons	Approximate relative costs: Tank at 5 cents per lb	Foundation 5 feet deep at $7.00 per cu yd	Total with 10% added for appurtenances and connections	Per thousand gals
20	20	47	1/4	1/4	9	$ 880	$540	$1560	$33
	30	71	1/4	1/4	12	1237	540	1960	28
	40	94	1/4	1/4	16	1590	540	2350	25
	50	118	5/16	1/4	20	2040	540	2840	24
25	20	74	1/4	1/4	12	1155	800	2150	29
	30	110	1/4	1/4	16	1595	800	2640	24
	40	147	5/16	1/4	21	2090	800	3180	22
	50	184	3/8	1/4	26	2640	800	3780	21
	60	221	7/16	3/8	34	3390	800	4600	21
	70	258	1/2	3/8	42	4210	800	5510	21
30	20	105	1/4	1/4	15	1450	1110	2820	27
	30	158	1/4	1/4	20	1980	1110	3400	22
	40	211	5/16	1/4	26	2640	1110	4130	20
	50	264	7/16	3/8	37	3700	1110	5300	20
	60	316	1/2	3/8	47	4680	1110	6370	20
	70	369	9/16	3/8	59	5870	1110	7680	21
	80	422	5/8	3/8	72	7200	1110	9150	22
	90	475	3/4	1/2	89	8920	1110	11350	24
	100	528	13/16	1/2	105	10550	1110	12830	24
	110	580	7/8	1/2	124	12400	1110	14890	26
	120	633	15/16	1/2	144	14400	1110	17090	27
35	20	144	1/4	1/4	18	1770	1480	3580	25
	30	215	5/16	1/4	25	2470	1480	4350	20
	40	287	3/8	3/8	37	3680	1480	5670	20
	50	359	1/2	3/8	48	4830	1480	6950	19
	60	431	9/16	3/8	61	6130	1480	8380	19
	70	502	11/16	1/2	80	8010	1480	10450	21
	80	574	3/4	1/2	98	9770	1480	12400	22
	90	646	7/8	1/2	118	11850	1480	14700	23
	100	718	15/16	1/2	141	14100	1480	17100	24
	110	790	1 1/16	1/2	166	16580	1480	19900	25
	120	862	1 1/8	5/8	195	19530	1480	23100	27
	130	934	1 3/16	5/8	225	22500	1480	26400	28
40	20	188	1/4	1/4	21	2150	1900	4450	24
	30	282	5/16	1/4	30	2990	1900	5490	19
	40	376	7/16	3/8	45	4500	1900	7040	19
	50	470	9/16	3/8	60	5980	1900	8670	19
	60	564	5/8	3/8	77	7750	1900	10620	19
	70	658	3/4	1/2	101	10120	1900	13220	20
	80	751	7/8	1/2	125	12500	1900	15850	21
	90	846	15/16	1/2	151	15140	1900	18750	22
	100	941	1 1/16	5/8	184	18400	1900	22350	24
	110	1035	1 1/8	5/8	216	21600	1900	25850	25
	120	1130	1 1/4	5/8	251	25100	1900	29700	26

Data for Steel Standpipes—Continued

Dia. in feet	Height in feet	Capacity in thousand gallons	Required thickness of lowest plate with stress not exceeding 10000 lbs, in	Thickness of bottom, inches	Approximate weight in net tons	Approximate relative costs: Tank at 5 cents per lb	Foundation 5 feet deep at $7.00 per cu yd	Total with 10% added for appurtenances and connections	Per thousand gals
45	20	238	1/4	1/4	25	2 480	2350	$5 320	23
	30	357	3/8	3/8	40	4 020	2350	7 030	20
	40	476	1/2	3/8	55	5 500	2350	8 650	18
	50	594	5/8	3/8	74	7 380	2350	10 700	18
	60	713	3/4	1/2	101	10 100	2350	13 700	19
	70	833	7/8	1/2	128	12 780	2350	16 640	20
	80	951	15/16	1/2	156	15 640	2350	19 800	21
	90	1070	1 1/16	5/8	193	19 360	2350	23 900	22
	100	1190	1 3/16	5/8	230	23 020	2350	27 900	23
50	20	293	5/16	1/4	30	2 970	2870	6 430	22
	30	440	7/16	3/8	50	4 950	2870	8 600	20
	40	586	9/16	3/8	68	6 820	2870	10 660	18
	50	733	11/16	1/2	97	9 680	2870	13 800	19
	60	880	13/16	1/2	124	12 430	2870	16 820	19
	70	1025	15/16	1/2	156	15 620	2870	20 300	20
	80	1170	1 1/16	5/8	198	19 800	2870	24 900	21
	90	1320	1 3/16	5/8	238	23 870	2870	29 400	22
60	20	423	5/16	1/4	38	3 830	4050	8 670	20
	30	633	1/2	3/8	66	6 600	4050	11 720	19
	40	846	5/8	3/8	91	9 120	4050	14 500	17
	50	1060	13/16	1/2	132	13 200	4050	19 000	18
	60	1270	15/16	1/2	170	17 030	4050	23 200	18
	70	1480	1 1/8	5/8	224	22 440	4050	29 200	20
	80	1690	1 1/4	5/8	276	27 600	4050	33 700	20
70	20	574	3/8	3/8	61	6 140	5400	12 700	22
	30	861	9/16	3/8	87	8 760	5400	15 600	18
	40	1150	3/4	1/2	133	13 370	5400	20 600	18
	50	1438	15/16	1/2	178	17 850	5400	25 600	18
	60	1725	1 1/8	5/8	241	24 160	5400	32 500	19

Overflows should invariably be provided for distributing reservoirs and should have sufficient capacity to discharge all the water that the pipes or pumps are capable of bringing to them. Many reservoirs have been lost and great damage done by failure to provide sufficient overflow capacity.

Standpipes are elevated reservoirs built of sheet steel entirely above the surface of the ground, and are commonly used where the desired water level is a considerable distance above the surface of the ground. The limitations of steel construction do not in general allow standpipes to be used in large works. Roofs should be provided on all standpipes holding waters deteriorating in the sunshine, that is, in general, for ground waters and filtered waters.

Reinforced concrete standpipes have been used with satisfactory results. It does not appear that any very large financial saving has been made by their use. Towers of masonry are frequently built about standpipes for ornamental purposes, and to protect them from wind pressure, and to make very tall standpipes small in diameter safe.

Elevated Steel Tanks supported on steel trestles are used in place of standpipes where the quantities of water to be stored are not large and the elevation above the surface of the ground is considerable. The East Providence tank holding 1 000 000 gallons, from 135 to 205 feet above the ground, was erected in 1904 at a cost of about $100 000. (N. E. W. W. A. vol. 19, p. 55). WOODEN TANKS are frequently used in railway supplies and in industrial operations, but are seldom to be recommended for public water supply.

The Distribution System includes all the main pipes and lateral pipes, the standpipes and distributing reservoirs, gates, meters, all services and connections as far as owned by the water department within and near the area that is actually served with water. The piping in a distribution system must be designed so that water can be supplied to any point at any time at the greatest rate at which water may be fairly demanded at that place.

Gridiron System. This is a system in which all pipes are connected with all other pipes at street intersections, so that in case of a fire at any point water comes to that point through pipes from all directions. This arrangement is more advantageous in supplying water for fire protection than the branching system, which would be sufficient and often best for supplying water for all purposes except fire service. The gridiron system is practically universal in American cities.

An economical system for the distribution of water for routine uses only would consist of a system of branching pipes, each branch being made sufficiently large to supply the water to the territory served by it at the time of day when use is greatest.

The Gridiron System avoids "dead ends" and insures circulation. Pipes are however laid below frost in the North Eastern States, with 4 to 5 feet of cover.

Gate Valves are placed at intervals on all pipe lines of considerable length. In city streets they are generally placed near intersections and so arranged, in the gridiron system, that any section may be shut out without interfering with the remainder while at the same time but a limited number of fire hydrants are affected. Outside the city valves are placed less frequently, and are best placed on summits where the pressure is least. The gates serve the purpose of facilitating tests of the pipe and shutting off portions of it for repairs in case of emergency.

Gates Smaller than the Pipe are often used on pipes 30 inches in diameter and over, connection being made by reducers on either side. The cost is less and the smaller gates are operated more quickly and easily. There is a little head lost, and the smaller the gate the more head is lost. This is controlling in determining how much smaller than the pipe it is best to make the gates.

Loss of Head in Gates with Taper Cone Connections

Diam. of gate, inches	Diameter of pipe in inches						
	30	36	42	48	54	60	72
20	1.57	3.47	6.59	....	....	....	.....
24	0.65	1.57	3.07	5.40	8.72	....	.....
30	0.15	0.52	1.14	2.09	3.47	5.40	11.45
36	....	0.15	0.44	0.91	1.57	2.51	5.40
42	....	....	0.15	0.40	0.75	1.25	2.83
48	....	....	....	0.15	0.35	0.65	1.57

The figures given are in velocity heads (or in feet, when the velocity in the main pipe is 8.03 ft. per sec.) They may also be taken as tenths of feet when the velocity in the main pipe is 2.54 ft. per sec.

Basis. Loss of head in a gate, 0.15, velocity head. Loss of head in cones, 0.20 of the amount that the velocity head at the throat is greater than the velocity head in the pipe.

The actual amount of head lost in a gate depends upon the form of gate, and considerable variations are to be anticipated with gates of different designs. The amount lost in the cones depends upon the taper design and smoothness of the surfaces, and considerable variations either way are to be anticipated.

Generally 24-inch gates may be used on 30 and 36 inch pipes, 30-inch gates on 42 and 48 inch pipes, and 36-inch gates on 60 and 72 inch pipes; but if head or elevation is very valuable the gate should be one size larger than above indicated.

The usual form of valve consists of a "Body" casting connected in the line of the pipe surmounted by a "Bonnet" a "Dome" connected to the body by flanges. The "Disc" rises into the dome when the gate is opened and is actuated by a screw stem of either "rising" or "non-rising" type.

The Disc is either wedge shaped fitting into corresponding grooves in the body or is made of two parallel plates which are forced apart by fold ing wedges, often the disc is seated in closing and vice versa in opening.

Water Consumption

Per Capita Consumption is the amount of water used per day for each person living in the city of area supplied on the basis of the annual average figures. In other words, it is the whole quantity of water supplied in gallons in one year, divided by 365 and divided by the total population of the district supplied with water.

Maximum Monthly Rate of Consumption. During that month in the year when the consumption is highest, from 15 to 25% more water is used than the average for the year. In some cases 40% more water is used

High monthly rates of consumption are usually associated with either a very dry period,with more than the usual sprinkling of streets and lawns or an exceptionally cold month, with a continued draft of water through many services to keep exposed and imperfectly protected pipes from freezing. Where services are metered the excess consumption in cold weather largely disappears. It is cheaper to cover the pipes or otherwise to protect them from freezing than to pay for the water that it is necessary to allow to run in order to protect them.

* Meters and Consumption

The general effect of meters is to reduce consumption generally by eliminating waste. It appears that the tendency is for an unmetered city to consume more than twice as much water as one which is metered.

One of the accompanying tables gives the percentage of consumption metered and the per capita consumption in each of the 155 cities of more than 30,000 population. These figures are compiled from statistics for the year 1915 published by the Census Board. Another table combines these figures showing the number of cities which meter all their water, and the average per capita consumption per day of the group: the same for those which meter between 90% and 99%, inclusive; and so on for all cities, grouped by 10 units of percentage of water metered.

Of the 26 cities reporting all water metered, only one had a per capita consumption greater than the average for all cities; of the 70 having more than ⅔ of the water metered, only 10 had a per capita consumption greater than the average for all cities. The average consumption for these 70 cities was 103 gallons, while that for the 47 cities showing less than ⅓ metered, was 161 gallons.

There are a few cities with fairly low consumption; also a few very completely metered ones with a rather high rate. But these averages all of the larger cities of the country (not a number of "hand picked" ones) show a most decided tendency of consumption rates to fall as meters are introduced. The more rapid drop for the first 25 to 30 percent of water metered apparently shows that metering persuades the large consumer to economize on water to a greater extent that it does the small ones.

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* Municipal Journal, June 1, 1916.

Meterage & Consumption in Larger Cities

CITY	Percent of Water Metered	Per Capita Consumption (a)	CITY	Percent of Water Metered	Per Capita Consumption (a)
Akron	30	156	Fall River	57	48
Albany	33	230	Fitchburg	100	104
Allentown	1	120	Flint	60	120
Altoona	6	108	Fort Wayne	100	64
Amsterdam	14	224	Fort Worth	100	79
Atlanta	100	113	Galveston	99	95
Atlantic City	98	156	Grand Rapids	60	123
Auburn	21	177	Hamilton	85	84
Augusta	9	196	Harrisburg	90	111
Aurora	75	99	Hartford	100	64
Austin	75	122	Haverhill	27	172
Baltimore	27	131	Hoboken	70	93
Bay City	30	172	Holyoke	29	112
Bayonne	100	120	Houston	58	86
Bellingham	25	162	Jackson	100	93
Binghamton	59	127	Jacksonville	95	89
Birmingham	100	b	Jamestown	65	77
Boston	46	111	Jersey City	24	149
Brockton	100	42	Joliet	90	201
Buffalo	32	342	Kalamazoo	100	64
Cambridge	33	86	Kansas City, Kan.	52	157
Camden	6	127	Kansas City, Mo.	71	149
Canton	35	124	Knoxville	47	220
Cedar Rapids	100	90	La Crosse	56	125
Charlotte	100	63	Lancaster	29	133
Chelsea	67	90	Lansing	80	106
Chicago	22	226	Lawrence	93	43
Cincinnati	61	130	Lima	80	147
Cleveland	99	118	Lincoln	100	78
Colorado Springs	2	180	Lorain	37	119
Columbia	100	141	Los Angeles	80	141
Columbus	95	92	Louisville	45	129
Council Bluffs	75	146	Lowell	56	99
Covington	100	46	Lynchburg	15	223
Dallas	50	115	Lynn	50	64
Dayton	100	117	McKeesport	66	113
Decatur	95	121	Macon	50	150
Denver	7	b	Malden	100	46
Detroit	42	189	Manchester	25	64
Dubuque	100	110	Memphis	60	87
Duluth	73	102	Milwaukee	72	110
E. Orange	44	68	Minneapolis	92	81
El Paso	90	69	Mobile	32	146
Erie	36	231	Montgomery	75	80
Evansville	18	164	Muskogee	88	92
Everett	46	72	Nashville	75	106

CITY	Percent of Water Metered	Per Capita Consumption (a)	CITY	Percent os Water Metered	Per Capita Consumption (a)
Newark	46	107	San Diego	100	137
New Bedford	96	72	San Francisco	7	b
New Britain	99	85	Savannah	2	140
New Orleans	100	74	Schenectady	11	130
Newport	66	60	Seattle	94	160
Newton	61	70	Sioux City	100	78
New York	26	102	Somerville	65	74
Niagara Falls	40	283	Spokane	65	246
Norfolk	80	94	South Bend	33	85
Oklahoma City	98	116	Springfield, Ill.	99	150
Omaha	96	118	Springfield, O.	48	155
Orange	100	72	Springfield, Mass.	60	103
Oshkosh	38	130	St. Louis	30	128
Pasadena	96	120	St. Paul	61	70
Pawtucket	90	62	Syracuse	99	147
Perth Amboy	55	193	Tacoma	8	430c
Philadelphia	8	182	Taunton	58	65
Pittsburgh	15	252	Toledo	90	118
Pittsfield	15	152	Topeka	100	89
Portland, Ore.	21	141	Trenton	22	153
Portland, Me.	20	130	Troy	12	314
Providence	70	65	Waco	33	141
Pueblo	7	295	Washington	59	161
Quincy	90	73	Waterbury	50	100
Reading	20	139	Waterloo	62	54
Richmond	70	105	Wheeling	6	309
Rochester	70	106	Wilmington, Del.	100	105
Rockford	100	58	Worcester	74	78
Sacramento	...	366	Woonsocket	98	34
Saginaw	15	330	Yonkers	100	91
Salem	25	89	Youngstown	33	134
Salt Lake City	33	203	Average	40	139

Metering Water and Average Consumption

Percent of Water Metered	Number of Cities	Water supplied, gallons per capita per day	Percent of Water Metered	Number of Cities	Water supplied, gallons per capita per day
100	26	85	40 to 49	9	138
90 to 99	23	109	30 to 39	15	184
80 to 89	6	128	20 to 29	15	142
70 to 79	13	103	10 to 19	8	235
60 to 69	14	113	0 to 9	13	195
50 to 59	13	117			

a—average amount of water supplied to distribution system daily, divided by population served.
b—not reported
c—about half this amount overflows from a low service reservoir and is allowed to run to waste.

Water Consumption

Maximum Weekly and Daily Rates. There will be some weeks and some days when the quantities will considerably exceed the average for the maximum month. Generally a maximum daily consumption of 10 or 15 gallons per capita in excess of the average for the maximum month must be expected.

Hourly Fluctuations in Flow. Water is required primarily for domestic and manufacturing purposes, and for these purposes is required in quantities that are fairly well determined and at times that do not vary very much from day to day. The greatest normal use of water is in the morning hours. The afternoon use is a little less. The night use of water is comparatively small.

Amount of Growth to be Anticipated. In designing pipe lines, it is necessary to anticipate growth to a certain extent in order to avoid the necessity of duplicating the lines at an early date. On the other hand, anticipating future growth to an unreasonable extent results in burdening present takers with the cost of facilities provided for the future to an unreasonable extent. In general, all new pipe lines should be designed to serve a population 50% greater than the present population, and in cases of special difficulty, where an additional line would be specially difficult or expensive, a greater growth than this should be anticipated.

Increasing the diameter of the pipe, 1% increases the carrying capacity 2.63%, and increases the cost of the pipe from 1% to 1.5%, according to the size and class of pipe and the conditions under which it is laid. On this basis adding 1% to the investment adds from 1.75% to 2.63% to the carrying capacity, $100 invested now in increasing the size of the pipe adds as much to the capacity as from $175 to $263 invested in a new pipe line at some time in the future if the new line is of the same size as the present one. $100 invested now at 5% will amount to $175 in 11 years and $263 in 20 years; at 4% the increase will be reached in 14 years and 25 years respectively. In general these represent economical limits of time to be anticipated.

As a general rule design should be made for ten or fifteen years only where the growth is over 3% per annum or where money is hard to get, and design for twenty or twenty-five years where growth is under 2% per annum or where money is obtainable at a low rate, and also in all cases where pipe is less than 12 inches in diameter or where pressure is light. There are many exceptions to this rule under peculiar conditions and it must be applied with caution.

Population that can be Supplied by Pipes of Various Sizes

Based on an average use of one hundred gallons per capita daily

Diameter of one pipe line, inches	For two or more pipes, sum of areas in sq. ins. Sectional area of pipe sq. ins.	With an average amount of fire service*			With no fire service. Maximum draft 170 gallons per capita daily		
		Flat slopes and long lines $V=2$	Average condition $V=3$	Steep slopes and short lines $V=4$	Flat slopes and long lines $V=2$	Average conditions $V=3$	Steep slopes and short lines $V=4$
4	13	12	27	48	660	990	1 330
6	28	61	132	228	1 490	2 240	2 950
8	50	182	392	666	2 650	3 980	5 320
10	79	425	900	1 500	4 150	6 190	8 280
12	113	835	1 720	2 850	5 950	8 950	12 000
16	201	2 320	4 620	7 400	10 600	15 900	21 300
20	314	4 940	9 520	14 900	16 500	24 800	33 200
24	452	8 900	16 700	25 500	23 900	35 800	47 800
30	707	17 200	32 000	48 000	37 400	56 100	74 800
36	1018	30 300	53 300	78 200	53 800	80 500	108 000
42	1385	46 600	80 400	117 000	73 200	110 000	146 000
48	1810	67 100	114 000	163 000	95 300	142 000	190 000
54	2290	91 600	153 000	219 000	121 000	181 000	242 000
60	2827	120 000	200 000	282 000	148 000	224 000	299 000

*Gallons daily = 120 pop. + 1 000 000 $\sqrt{\text{Pop. in thousands.}}$

Fire Protection

The Requirements of Fire Service vary greatly. In European cities, with fire-proof buildings, but little water is required for the extinguishment of fire. In tropical countries, where buildings are widely separated and represent but small value, and often in wet climates, it does not pay to furnish fire service. It is better to let buildings burn now and then than to provide long and larger pipes and other equipment that would be required for fire service. In American cities wooden construction is common and wooden floors are used in many buildings having brick walls. A large pipe capacity is required to provide the water which is required for extinguishing fires in such buildings.

The Amount of Water required for extinguishing fires is not very large in the aggregate, but when fires occur it is wanted at a high rate, and pipes must therefore be provided of large capacity to meet this demand. Pipe sizes required for fire protection in American cities are always larger than those required for other uses, and the size of pipe to be selected within the area of the distribution system, and between it and the distributing reservoir or pumping station where direct pumping is used, is mainly controlled by questions of fire protection.

Water Required for Fire Service. The amount of water to be provided for fire service depends upon the size and number of fire steams required in a given area.

For Average American Conditions, take the square root of the population in thousands and this indicates the rate in millions of gallons of water per day at which water should be provided for fire service.

For example: If the population is 9 thousand allow water at a rate of 3 million gallons per day for fire service. If the population is 25 thousand allow 5 million gallons per day, and if 100 thousand allow 10 million gallons of water per day.

The pipes must be designed large enough so that the quantity of water for fire service will be available even though the fire occurs at a time when water is being used at a high rate for other purposes. It is not necessary to assume the extreme maximum rate of draft for other purposes; some chances can be taken. To find the required capacity add, first, the average annual rate of consumption; second, 20 gallons per capita to cover ordinary fluctuations; third, the amount of water allowed for fire protection. If the fluctuations are unusually great, take 30 or 40 gallons per capita in place of 20.

Concentration of Water for Fire Service. In the case of cities up to 100 000 inhabitants it is generally necessary to provide pipe capacity so that the whole amount of water provided for fire protection can be delivered with some loss of pressure in the neighborhood of the closest, largest, highest and most valuable buildings, and at each of such points if there are several; elsewhere piping capable of delivering smaller quantities varying with the kind and value of construction and the proximity of the various buildings.

This table may be used as a very general guide. With high per capita consumption and bad fire conditions the sizes should be increased. Under opposite conditions they may be reduced. It will often pay to make pipe sizes a little smaller in the distribution and larger in the supply mains without changing the total capacity of the system.

A Standard Fire Stream is one flowing 250 gallons per minute through a smooth nozzle 1⅛ inches in diameter, with a pressure at the base of the tip of 45 pounds. Such a stream is effective to a height of 70 feet above the ground or with a horizontal carry not exceeding 63 feet. When fed through the best quality 2½-inch rubber-lined hose the hydrant pressure required to throw such a stream taken while the stream is running is as follows:

Feet of hose =	50	100	200	400	600
Lb. per sq. in =	56	63	77	106	135

The hydrant pressure is less during the fire than at other times, because more head is lost in friction in the pipes, and the ordinary pressure must be greater to insure standard conditions during fire. The best hydrant pressure for general use is considered to be from 80 to 100 lbs., but as other conditions are frequently controlling, fire service must be largely adapted to what is available.

The best statement of the hydraulics of fire streams and nozzles is in a paper by John R. Freeman, Trans. Am. Soc. C. E., 1889, vol. 21, P. 303.

Data Useful in Steel Conduit Design

TABLES

FOR THE

REDUCTION OF

SLOPE MEASUREMENTS

TO

HORIZONTAL DISTANCES

FROM 10 TO 100 FEET,
WITH DIFFERENCE OF LEVEL
FROM 0.0 TO 20.0 FEET

SLOPE DISTANCES IN FEET AT TOP OF PAGE.

DIFFERENCES OF ELEVATION, IN FEET IN TENTHS, IN SIDE COLUMNS.

TABLE OF CORRECTIONS IN BODY OF SHEET, CARRIED TO FEET, TENTHS, HUNDREDS AND THOUSANDTHS OF A FOOT.

EXAMPLE:

GIVEN A SLOPE MEASUREMENT OF 80 FEET, WITH A DIFFERENCE OF LEVEL OF 2.1 FEET, TO ASCERTAIN THE HORIZONTAL DISTANCE—

FROM THE TABLE, UNDER 80 AND OPPOSITE 2.1, FIND .028 FEET, THE CORRECTION TO BE DEDUCTED:

THEN 80.00—.028—79.972 FEET, THE CORRECT HORIZONTAL DISTANCE.

	10	20	30	40	50	60	70	80	90	100	
0.0											0.0
.1	.001	......	......	......	......	......	......	......	......	......	.1
.2	.002	.001	.001	.001	......	......	......	......	......	......	.2
.3	.005	.002	.002	.001	.001	.001	.001	.001	.001	.001	.3
.4	.008	.004	.003	.002	.001	.001	.001	.001	.001	.001	.4
0.5	.013	.006	.004	.003	.003	.002	.002	.002	.001	.001	0.5
.6	.018	.009	.006	.005	.004	.003	.003	.002	.002	.002	.6
.7	.025	.012	.008	.006	.005	.004	.004	.003	.003	.003	.7
.8	.032	.016	.011	.008	.006	.005	.005	.004	.004	.003	.8
.9	.041	.020	.014	.010	.008	.007	.006	.005	.005	.004	.9
1.0	.050	.025	.017	.013	.010	.008	.007	.006	.006	.005	1.0
.1	.061	.030	.020	.015	.012	.010	.008	.008	.007	.006	.1
.2	.072	.036	.024	.018	.014	.012	.010	.009	.008	.007	.2
.3	.085	.042	.028	.021	.017	.014	.012	.011	.009	.009	.3
.4	.099	.049	.033	.025	.020	.016	.014	.012	.011	.010	.4
1.5	.113	.056	.038	.028	.023	.019	.016	.014	.013	.011	1.5
.6	.129	.064	.043	.032	.026	.021	.018	.016	.014	.013	.6
.7	.146	.072	.048	.036	.029	.024	.021	.018	.016	.015	.7
.8	.163	.081	.054	.041	.032	.027	.023	.020	.018	.016	.8
.9	.182	.090	.060	.045	.036	.030	.026	.023	.020	.018	.9
2.0	.202	.100	.067	.050	.040	.033	.029	.025	.022	.020	2.0
.1	.223	.111	.074	.055	.044	.037	.032	.028	.025	.022	.1
.2	.245	.121	.081	.061	.048	.040	.035	.030	.027	.024	.2
.3	.268	.133	.088	.066	.053	.044	.038	.033	.029	.027	.3
.4	.292	.145	.096	.072	.058	.048	.041	.036	.032	.029	.4
2.5	.317	.157	.104	.078	.063	.052	.045	.039	.035	.031	2.5
.6	.344	.170	.113	.085	.068	.056	.048	.042	.038	.034	.6
.7	.371	.183	.122	.091	.073	.061	.052	.046	.041	.037	.7
.8	.400	.197	.131	.098	.079	.065	.056	.049	.044	.039	.8
.9	.429	.211	.141	.105	.086	.070	.060	.053	.047	.042	.9
3.0	.460	.226	.150	.113	.090	.075	.064	.056	.050	.045	3.0
.1	.493	.242	.161	.120	.096	.080	.069	.060	.053	.048	.1
.2	.526	.258	.171	.128	.103	.085	.073	.064	.057	.051	.2
.3	.560	.274	.182	.136	.109	.091	.078	.068	.061	.055	.3
.4	.596	.291	.193	.145	.116	.096	.083	.072	.064	.058	.4
3.5	.633	.309	.205	.153	.123	.102	.088	.077	.068	.061	3.5
.6	.671	.327	.217	.162	.130	.108	.093	.081	.072	.065	.6
.7	.710	.345	.229	.172	.137	.114	.098	.085	.076	.069	.7
.8	.750	.364	.242	.181	.145	.120	.103	.090	.080	.072	.8
.9	.792	.384	.255	.191	.152	.127	.109	.095	.085	.076	.9
4.0	.835	.404	.268	.201	.160	.133	.114	.100	.089	.080	4.0

	10	20	30	40	50	60	70	80	90	100	
4.1	.879	.425	.282	.211	.168	.140	.120	.105	.093	.084	4.1
.2	.925	.446	.295	.221	.177	.147	.126	.110	.098	.088	.2
.3	.972	.468	.310	.232	.185	.154	.132	.116	.103	.092	.3
.4	1.020	.490	.324	.243	.194	.162	.138	.121	.108	.097	.4
4.5	1.070	.513	.339	.254	.203	.169	.145	.127	.113	.101	4.5
.6	1.121	.536	.355	.265	.212	.176	.151	.132	.118	.106	.6
.7	1.173	.560	.370	.277	.222	.184	.158	.138	.123	.111	.7
.8	1.227	.584	.387	.289	.231	.192	.165	.144	.128	.115	.8
.9	1.283	.609	.403	.301	.241	.200	.172	.150	.134	.120	.9
5.0	1.340	.635	.420	.314	.251	.209	.179	.157	.139	.125	5.0
.1	1.398	.661	.437	.326	.261	.217	.186	.163	.145	.130	.1
.2	1.458	.688	.454	.339	.271	.226	.193	.169	.150	.135	.2
.3	1.520	.715	.472	.353	.282	.235	.201	.176	.156	.141	.3
.4	1.583	.743	.490	.366	.293	.244	.209	.183	.162	.146	.4
5.5	1.648	.771	.508	.380	.303	.253	.216	.189	.168	.151	5.5
.6	1.715	.800	.527	.394	.314	.262	.224	.196	.174	.157	.6
.7	1.784	.829	.546	.408	.326	.271	.233	.203	.181	.163	.7
.8	1.854	.859	.566	.423	.338	.281	.241	.211	.187	.168	.8
.9	1.926	.890	.586	.438	.349	.291	.249	.218	.194	.174	.9
6.0	2.000	.921	.606	.453	.361	.301	.258	.225	.200	.180	6.0
.1	2.076	.953	.627	.468	.374	.311	.266	.233	.207	.186	.1
.2	2.154	.985	.648	.483	.386	.321	.275	.241	.214	.192	.2
.3	2.234	1.018	.669	.499	.399	.332	.284	.249	.221	.199	.3
.4	2.316	1.052	.690	.515	.411	.342	.293	.256	.228	.205	.4
6.5	2.400	1.086	.713	.532	.424	.353	.303	.265	.235	.212	6.5
.6	2.487	1.120	.735	.548	.438	.364	.312	.273	.242	.218	.6
.7	2.576	1.155	.758	.565	.451	.375	.321	.281	.250	.225	.7
.8	2.668	1.191	.781	.582	.465	.386	.331	.290	.257	.232	.8
.9	2.762	1.228	.806	.600	.478	.398	.341	.298	.265	.238	.9
7.0	2.869	1.265	828	.617	.492	.410	.351	.307	.273	.245	7.0
.1	2.968	1.302	.852	.635	.507	.422	.361	.316	.281	.252	.1
.2	3.060	1.341	.877	.653	.521	.434	.371	.325	.289	.260	.2
.3	3.166	1.380	.902	.672	.536	.446	.382	.334	.297	.267	.3
.4	3.274	1.419	.927	.690	.551	.458	.392	.343	.305	.274	.4
7.5	3.386	1.459	.953	.709	.566	.471	.403	.352	.313	.282	7.5
.6	3.511	1.500	.979	.729	.581	.483	.414	.362	.322	.289	.6
.7	3.620	1.542	1.005	.748	.596	.496	.425	.372	.330	.297	.7
.8	3.742	1.584	1.032	.768	.612	.509	.436	.381	.339	.305	.8
.9	3.869	1.626	1.059	.788	.628	.522	.447	.391	.347	.313	.9
8.0	4.000	1.670	1.086	.808	.644	.536	.459	.401	.356	.321	8.0

	10	20	30	40	50	60	70	80	90	100	
8.1	4.136	1.714	1.114	.829	.660	.549	.470	.411	.365	.329	.1
.2	4.276	1.758	1.142	.850	.677	.563	.482	.421	.374	.337	.2
.3	4.422	1.803	1.171	.871	.694	.577	.494	.432	.384	.345	.3
.4	4.574	1.849	1.200	.892	.711	.591	.506	.442	.393	.353	.4
8.5	4.732	1.896	1.229	.913	.728	.605	.518	.453	.402	.362	8.5
.6	4.897	1.943	1.259	.935	.745	.620	.530	.464	.412	.371	.6
.7	5.069	1.991	1.289	.958	.763	.634	.543	.475	.422	.379	.7
.8	5.250	2.040	1.320	.980	.780	.649	.555	.486	.431	.388	.8
.9	5.440	2.089	1.351	1.003	.798	.664	.568	.497	.441	.397	.9
9.0	5.641	2.139	1.382	1.026	.817	.679	.581	.508	.451	.406	9.0
.1	5.854	2.190	1.413	1.049	.835	.694	.594	.519	.461	.415	.1
.2	6.081	2.242	1.445	1.072	.854	.710	.607	.531	.471	.424	.2
.3	6.324	2.294	1.478	1.096	.872	.725	.621	.542	.482	.433	.3
.4	6.588	2.347	1.511	1.120	.891	.741	.634	.554	.492	.443	.4
9.5	6.877	2.400	1.544	1.144	.911	.757	.648	.566	.503	.452	9.5
.6	7.200	2.455	1.577	1.169	.930	.773	.661	.578	.514	.462	.6
.7	7.569	2.510	1.611	1.194	.950	.789	.675	.590	.524	.472	.7
.8	8.010	2.565	1.646	1.219	.970	.806	.689	.603	.535	.481	.8
.9	8.589	2.622	1.681	1.244	.990	.822	.704	.615	.546	.491	.9
10.0	10.000	2.679	1.716	1.270	1.010	.839	.718	.627	.557	.501	10.0
.1	......	....	1.751	1.296	1.031	.856	.733	.640	.569	.511	.1
.2	......	....	1.787	1.322	1.051	.873	.747	.653	.580	.521	.2
.3	......	....	1.823	1.349	1.072	.891	.762	.666	.591	.532	.3
.4	......	....	1.860	1.375	1.094	.908	.777	.679	.602	.542	.4
10.5	......	....	1.897	1.402	1.115	.926	.792	.692	.614	.553	10.5
.6	......	....	1.935	1.430	1.136	.944	.807	.705	.626	.563	.6
.7	......	....	1.973	1.458	1.158	.962	.823	.719	.638	.574	.7
.8	......	....	2.012	1.486	1.180	.980	.838	.732	.650	.585	.8
.9	......	....	2.051	1.514	1.202	.998	.854	.746	.663	.596	.9
11.0	......	....	2.089	1.542	1.225	1.017	.870	.760	.675	.607	11.0
.1	......	....	2.129	1.571	1.248	1.036	.886	.774	.687	.618	.1
.2	......	....	2.169	1.600	1.271	1.055	.902	.788	.700	.629	.2
.3	......	....	2.209	1.629	1.294	1.074	.918	.802	.712	.640	.3
.4	......	....	2.250	1.659	1.317	1.093	.935	.816	.725	.652	.4
11.5	......	....	2.292	1.689	1.340	1.112	.951	.831	.738	.663	11.5
.6	......	....	2.333	1.719	1.364	1.132	.968	.845	.751	.675	.6
.7	......	....	2.375	1.749	1.388	1.152	.985	.860	.764	.687	.7
.8	......	....	2.418	1.780	1.412	1.172	1.002	.875	.777	.699	.8
.9	......	....	2.461	1.811	1.437	1.192	1.019	.890	.790	.711	.9
12.0	......	....	2.505	1.842	1.461	1.212	1.036	.905	.804	.723	12.0

	10	20	30	40	50	60	70	80	90	100	
12.1	....	....	2.548	1.874	1.486	1.232	1.054	.920	.817	.735	12.1
.2	....	....	2.593	1.906	1.511	1.253	1.071	.936	.831	.747	.2
.3	....	....	2.637	1.938	1.536	1.274	1.089	.951	.844	.759	.3
.4	....	....	2.683	1.971	1.562	1.295	1.107	.967	.858	.772	.4
12.5	....	....	2.728	2.003	1.588	1.316	1.125	.983	.872	.784	12.5
.6	....	....	2.774	2.036	1.614	1.338	1.143	.999	.886	.797	.6
.7	....	....	2.821	2.070	1.640	1.359	1.162	1.015	.901	.810	.7
.8	....	....	2.867	2.103	1.666	1.381	1.180	1.031	.915	.823	.8
.9	....	....	2.915	2.137	1.693	1.403	1.199	1.047	.929	.836	.9
13.0	....	....	2.963	2.171	1.720	1.425	1.218	1.063	.944	.849	13.0
.1	....	....	3.011	2.206	1.747	1.448	1.237	1.080	.959	.862	.1
.2	....	....	3.060	2.241	1.774	1.470	1.256	1.097	.973	.875	.2
.3	....	....	3.109	2.276	1.801	1.492	1.275	1.113	.988	.888	.3
.4	....	....	3.159	2.311	1.829	1.515	1.294	1.130	1.003	.902	.4
13.5	....	....	3.209	2.347	1.857	1.538	1.314	1.147	1.018	.915	13.5
.6	....	....	3.260	2.383	1.885	1.561	1.334	1.164	1.034	.929	.6
.7	....	....	3.311	2.419	1.914	1.585	1.354	1.182	1.049	.943	.7
.8	....	....	3.362	2.456	1.942	1.608	1.374	1.199	1.064	.957	.8
.9	....	....	3.414	2.493	1.971	1.632	1.394	1.217	1.080	.971	.9
14.0	....	....	3.467	2.530	2.000	1.656	1.414	1.235	1.096	.985	14.0
.1	....	....	3.520	2.567	2.029	1.680	1.435	1.252	1.111	.999	.1
.2	....	....	3.573	2.605	2.059	1.704	1.455	1.270	1.127	1.013	.2
.3	....	....	3.627	2.643	2.089	1.729	1.476	1.288	1.143	1.028	.3
.4	....	....	3.682	2.682	2.119	1.754	1.497	1.307	1.159	1.042	.4
14.5	....	....	3.737	2.721	2.149	1.778	1.518	1.325	1.176	1.057	14.5
.6	....	....	3.792	2.760	2.179	1.803	1.539	1.344	1.192	1.072	.6
.7	....	....	3.848	2.799	2.210	1.829	1.561	1.362	1.209	1.086	.7
.8	....	....	3.904	2.839	2.241	1.854	1.592	1.381	1.225	1.101	.8
.9	....	....	3.961	2.879	2.272	1.879	1.604	1.400	1.242	1.116	.9
15.0	....	....	4.019	2.919	2.303	1.905	1.626	1.419	1.259	1.131	15.0
.1	....	....	.....	2.960	2.335	1.931	1.648	1.438	1.276	1.147	.1
.2	....	....	.....	3.001	2.366	1.957	1.670	1.457	1.293	1.162	.2
.3	....	....	.....	3.042	2.398	1.983	1.692	1.477	1.310	1.177	.3
.4	....	....	.....	3.083	2.431	2.010	1.715	1.496	1.327	1.193	.4
15.5	....	....	.....	3.124	2.463	2.037	1.738	1.516	1.345	1.208	15.5
.6	....	....	.....	3.167	2.496	2.063	1.760	1.536	1.362	1.224	.6
.7	....	....	.....	3.210	2.529	2 090	1.783	1.556	1.380	1.240	.7
.8	....	....	.....	3.253	2.562	2.117	1.806	1.576	1.398	1.256	.8
.9	....	....	.....	3.296	2.596	2.145	1.830	1.596	1.416	1.272	.9
16.0	....	....	.....	3.339	2.629	2.173	1.853	1.616	1.434	1.288	16.0

	10	20	30	40	50	60	70°	80	90	100	
16.1	.....	.....	.....	3.383	2.663	2.200	1.877	1.637	1.452	1.305	16.1
.2	.....	.....	.....	3.427	2.697	2.228	1.900	1.657	1.470	1.321	.2
.3	.....	.....	.....	3.472	2.732	2.256	1.924	1.678	1.488	1.337	.3
.4	.....	.....	.....	3.517	2.766	2.285	1.948	1.899	1.507	1.354	.4
16.5	.....	.....	.....	3.562	2.801	2.313	1.972	1.720	1.526	1.371	16.5
.6	.....	.....	.....	3.608	2.836	2.342	1.997	1.741	1.544	1.387	.6
.7	.....	.....	.....	3.653	2.871	2.371	2.021	1.762	1.563	1.404	.7
.8	.....	.....	.....	3.699	2.907	2.400	2.046	1.784	1.582	1.421	.8
.9	.....	.....	.....	3.746	2.943	2.429	2.071	1.805	1.601	1.438	.9
17.0	.....	.....	.....	3.792	2.979	2.459	2.096	1.827	1.620	1.456	17.0
.1	.....	.....	.....	3.839	3.015	2.488	2.121	1.849	1.639	1.473	.1
.2	.....	.....	.....	3.887	3.051	2.518	2.146	1.871	1.659	1.490	.2
.3	.....	.....	.....	3.935	3.088	2.548	2.171	1.893	1.678	1.508	.3
.4	.....	.....	.....	3.982	3.125	2.578	2.197	1.915	1.698	1.525	.4
17.5	.....	.....	.....	4.031	3.162	2.609	2.223	1.937	1.718	1.543	17.5
.6	.....	.....	.....	4.080	3.200	2.639	2.249	1.960	1.738	1.561	.6
.7	.....	.....	.....	4.129	3.238	2.670	2.275	1.983	1.758	1.579	.7
.8	.....	.....	.....	4.179	3.276	2.701	2.301	2.005	1.778	1.597	.8
.9	.....	.....	.....	4.229	3.314	2.732	2.327	2.028	1.798	1.615	.9
18.0	.....	.....	.....	4.279	3.352	2.764	2.354	2.051	1.818	1.633	18.0
.1	.....	.....	.....	4.329	3.391	2.795	2.381	2.074	1.839	1.652	.1
.2	.....	.....	.....	4.380	3.430	2.827	2.407	2.098	1.859	1.670	.2
.3	.....	.....	.....	4.432	3.469	2.859	2.434	2.122	1.880	1.689	.3
.4	.....	.....	.....	4.483	3.509	2.891	2.461	2.145	1.901	1.707	.4
18.5	.....	.....	.....	4.535	3.548	2.923	2.489	2.168	1.922	1.726	18.5
.6	.....	.....	.....	4.588	3.588	2.956	2.516	2.192	1.943	1.745	.6
.7	.....	.....	.....	4.640	3.628	2.988	2.544	2.216	1.964	1.764	.7
.8	.....	.....	.....	4.693	3.669	3.021	2.572	2.240	1.985	1.783	.8
.9	.....	.....	.....	4.747	3.710	3.054	2.600	2.265	2.007	1.802	.9
19.0	.....	.....	.....	4.801	3.751	3.088	2.628	2.289	2.028	1.822	19.0
.1	.....	.....	.....	4.855	3.792	3.121	2.656	2.314	2.050	1.841	.1
.2	.....	.....	.....	4.909	3.833	3.155	2.685	2.338	2.072	1.861	.2
.3	.....	.....	.....	4.964	3.875	3.189	2.713	2.363	2.094	1.880	.3
.4	.....	.....	.....	5.019	3.917	3.223	2.742	2.388	2.116	1.900	.4
19.5	.....	.....	.....	5.075	3.959	3.257	2.771	2.413	2.138	1.920	19.5
.6	.....	.....	.....	5.131	4.002	3.291	2.800	2.438	2.160	1.940	.6
.7	.....	.....	.....	5.187	4.045	3.326	2.829	2.463	2.182	1.960	.7
.8	.....	.....	.....	5.244	4.088	3.361	2.858	2.489	2.205	1.980	.8
.9	.....	.....	.....	5.301	4.131	3.396	2.888	2.514	2.227	2.000	.9
20.0	.....	.....	.....	5.359	4.174	3.431	2.918	2.540	2.250	2.020	20.0

Constants for Cut of 1 deg. for Different Diams.

Diam.	$\frac{3}{16}''$ Pl.	¼″ Pl.	$\frac{5}{16}''$ Pl.	⅜″ Pl.	$\frac{7}{16}''$ Pl.	½″ Pl.
Inches	Inches	Inches	Inches	Inches	Inches	Inches
20	.3555	.3577	.3599	.3621	.3643	.3665
21	.37295	.37515	.37735	.37955	.38175	.38395
22	.3904	.3926	.3948	.3970	.3992	.4014
23	.40785	.41005	.41225	.41445	.41665	.41885
24	.4253	.4275	.4297	.4319	.4341	.4363
25	.44275	.44495	.44715	.44935	.45155	.45375
26	.46020	.46240	.46460	.46680	.46900	.47120
27	.47765	.47985	.48205	.48425	.48645	.48860
28	.4951	.4973	.4995	.5017	.5039	.5061
29	.51255	.51475	.51695	.51915	.52135	.52355
30	.5300	.5322	.5344	.5366	.5388	.5410
31	.54745	.54965	.55185	.55405	.55625	.55845
32	.56490	.56710	.56930	.57150	.57370	.57590
33	.5824	.5846	.5868	.5890	.5912	.5934
34	.59985	.60205	.60425	.60645	.60865	.61085
35	.61730	.61950	.62170	.62390	.62610	.62830
36	.6347	.6369	.6391	.6413	.6435	.6457
37	.65215	.65435	.65455	.65875	.66095	.66315
38	.66960	.67180	.67400	.67620	.67840	.68060
39	.6870	.6892	.6914	.6936	.6958	.6980
40	.70445	.70665	.70885	.71105	.71325	.71545
41	.72190	.72415	.72630	.72840	.73070	.73290
42	.7394	.7416	.7438	.7460	.7482	.7504
43	.75685	.75905	.76125	.76345	.76565	.76785
44	.77430	.77650	.77870	.78090	.78310	.78530
45	.7919	.7941	.7963	.7985	.8007	.8029
46	.80935	.81155	.81375	.81595	.81815	.82035
47	.82680	.82900	.83120	.83340	.83560	.83780
48	.8442	.8464	.8486	.8508	.8530	.8552
49	.86165	.86385	.86605	.86825	.87045	.87265
50	.87910	.88130	.88350	.88570	.88790	.89010
51	.8965	.8982	.9004	.9026	.9050	.9072
52	.91395	.91565	.91785	.92005	.92245	.92405
53	.93140	.93310	.93530	.93750	.93990	.94150
54	.9489	.9511	.9533	.9555	.9577	.9599
55	.96635	.96855	.97075	.97295	.97315	.97735
56	.98380	.98600	.98820	.99040	.99260	.99480
57	1.0012	1.0034	1.0056	1.0078	1.0100	1.0122
58	1.01865	1.02085	1.02305	1.02525	1.02745	1.02965
59	1.03610	1.03830	1.04050	1.04270	1.04490	1.04710
60	1.0536	1.0558	1.0580	1.0602	1.0624	1.0646
61	1.07105	1.07325	1.07545	1.07765	1.07985	1.08205
62	1.08850	1.09070	1.09290	1.09510	1.09730	1.09950
63	1.1059	1.1081	1.1103	1.1125	1.1147	1.1169
64	1.12335	1.12555	1.12775	1.12995	1.13215	1.13435
65	1.14080	1.14300	1.14520	1.14740	1.14960	1.15180
66	1.1583	1.1605	1.1627	1.1649	1.1671	1.1693
67	1.17575	1.17795	1.18015	1.18235	1.18455	1.18675
68	1.19320	1.19540	1.19760	1.19980	1.20200	1.20420
69	1.2106	1.2128	1.2150	1.2172	1.2194	1.2216
70	1.22805	1.23025	1.23245	1.23465	1.23685	1.23905
71	1.24550	1.24770	1.24990	1.25210	1.25430	1.25650
72	1.2629	1.2651	1.2673	1.2695	1.2717	1.2739

Diam.	Circum.	Area
16.	50.265	201.06
⅛	50.658	204.22
¼	51.051	207.39
⅜	51.444	210.60
½	51.836	213.82
⅝	52.229	217.08
¾	52.622	220.35
⅞	53.014	223.65
17.	53.407	226.98
⅛	53.800	230.33
¼	54.192	233.71
⅜	54.585	237.10
½	54.978	240.53
⅝	55.371	243.98
¾	55.763	247.45
⅞	56.156	250.95
18.	56.549	254.47
⅛	56.941	258.02
¼	57.334	261.59
⅜	57.727	265.18
½	58.119	268.80
⅝	58.512	272.45
¾	58.905	276.12
⅞	59.298	279.81
19.	59.690	283.53
⅛	60.083	287.27
¼	60.476	291.04
⅜	60.868	294.83
½	61.261	298.65
⅝	61.654	302.49
¾	62.046	306.35
⅞	62.439	310.24
20.	62.832	314.16
⅛	63.225	318.10
¼	63.617	322.06
⅜	64.010	326.05
½	64.403	330.06
⅝	64.795	334.10
¾	65.188	338.16
⅞	65.581	342.25
21.	65.973	346.36
⅛	66.366	350.50
¼	66.759	354.66
⅜	67.152	358.84
½	67.544	363.05
⅝	67.937	367.28
¾	68.330	371.54
⅞	68.722	375.83
22.	69.115	380.13
⅛	69.508	384.46
¼	69.900	388.82
⅜	70.293	393.20
½	70.686	397.61
⅝	71.079	402.04
¾	71.471	406.49
⅞	71.864	410.97
23.	72.257	415.48

Diam.	Circum.	Area
23.		
⅛	72.649	420.00
¼	73.042	424.56
⅜	73.435	429.13
½	73.827	433.74
⅝	74.220	438.36
¾	74.613	443.01
⅞	75.006	447.69
24.	75.398	452.39
⅛	75.791	457.11
¼	76.184	461.86
⅜	76.576	466.64
½	76.969	471.44
⅝	77.362	476.26
¾	77.754	481.11
⅞	78.147	485.98
25.	78.540	490.87
⅛	78.933	495.79
¼	79.325	500.74
⅜	79.718	505.71
½	80.111	510.71
⅝	80.503	515.72
¾	80.896	520.77
⅞	81.289	525.84
26.	81.681	530.93
⅛	82.074	536.05
¼	82.467	541.19
⅜	82.860	546.35
½	83.252	551.55
⅝	83.645	556.76
¾	84.038	562.00
⅞	84.430	567.27
27.	84.823	572.56
⅛	85.216	577.87
¼	85.608	583.21
⅜	86.001	588.57
½	86.394	593.96
⅝	86.786	599.37
¾	87.179	604.81
⅞	87.572	610.27
28.	87.965	615.75
⅛	88.357	621.26
¼	88.750	626.80
⅜	89.143	632.36
½	89.535	637.94
⅝	89.928	643.55
¾	90.321	649.18
⅞	90.713	654.84
29.	91.106	660.52
⅛	91.499	666.23
¼	91.892	671.96
⅜	92.284	677.71
½	92.677	683.49
⅝	93.070	689.30
¾	93.462	695.13
⅞	93.855	700.98
30.	94.248	706.86
⅛	94.640	712.76

Diam.	Circum.	Area
30.		
¼	95 033	718.69
⅜	95.426	724.64
½	95.819	730.62
⅝	96.211	736.62
¾	96.604	742.64
⅞	96.997	748.69
31.	97.389	754.77
⅛	97.782	760.87
¼	98.175	766.99
⅜	98.567	773.14
½	98.960	779.31
⅝	99.353	785.51
¾	99.746	791.73
⅞	100.138	797.98
32.	100.531	804.25
⅛	100.924	810.54
¼	101.316	816.86
⅜	101.709	823.21
½	102.102	829.58
⅝	102.494	835.97
¾	102.887	842.39
⅞	103.280	848.83
33.	103.673	855.30
⅛	104.065	861.79
¼	104.458	868.31
⅜	104.851	874.85
½	105.243	881.41
⅝	105.636	888.00
¾	106.029	894.62
⅞	106.421	901.26
34.	106.814	907.92
⅛	107.207	914.61
¼	107.600	921.32
⅜	107.992	928.06
½	108.385	934.82
⅝	108.778	941.61
¾	109.170	948.42
⅞	109.563	955.25
35.	109.956	962.11
⅛	110.348	969.00
¼	110.741	975.91
⅜	111.134	982.84
½	111.527	989.80
⅝	111.919	996.78
¾	112.312	1003.8
⅞	112.705	1010.8
36.	113.097	1017.9
⅛	113.490	1025.0
¼	113.883	1032.1
⅜	114.275	1039 2
½	114.668	1046.3
⅝	115.061	1053.5
¾	115.454	1060.7
⅞	115.846	1068.0
37.	116.239	1075.2
⅛	116.632	1082.5
¼	117.024	1089.8

Diam.	Circum.	Area	Diam.	Circum.	Area	Diam.	Circum.	Area
37.			**44.**			**51.**		
⅜	117.417	1097.1	½	139.801	1555.3	⅝	162.185	2093.2
½	117.810	1104.5	⅝	140.194	1564.0	¾	162.577	2103.3
⅝	118.202	1111.8	¾	140.586	1572.8	⅞	162.970	2113.5
¾	118.596	1119.2	⅞	140.979	1581.6	**52.**	163.363	2123.7
⅞	118.988	1126.7	**45.**	141.372	1590.4	⅛	163.756	2133.9
38.	119.381	1134.1	⅛	141.764	1599.3	¼	164.148	2144.2
⅛	119.773	1141.6	¼	142.157	1608.2	⅜	164.541	2154.5
¼	120.166	1149.1	⅜	142.550	1617.0	½	164.934	2164.8
⅜	120.559	1156.6	½	142.942	1626.0	⅝	165.326	2175.1
½	120.951	1164.2	⅝	143.335	1634.9	¾	165.719	2185.4
⅝	121.344	1171.7	¾	143.728	1643.9	⅞	166.112	2195.8
¾	121.737	1179.3	⅞	144.121	1652.9	**53.**	166.504	2206.2
⅞	122.129	1186.9	**46.**	144.513	1661.9	⅛	166.897	2216.6
39.	122.522	1194.6	⅛	144.906	1670.9	¼	167.290	2227.0
⅛	122.915	1202.3	¼	145.299	1680.0	⅜	167.683	2237.5
¼	123.308	1210.6	⅜	145.691	1689.1	½	168.075	2248.0
⅜	123.700	1217.7	½	146.084	1698.2	⅝	168.468	2258.5
½	124.093	1225.4	⅝	146.477	1707.4	¾	168.861	2269.1
⅝	124.486	1233.2	¾	146.869	1716.5	⅞	169.253	2279.6
¾	124.878	1241.0	⅞	147.262	1725.7	**54.**	169.646	2290.2
⅞	125.271	1248.8	**47.**	147.655	1734.9	⅛	170.039	2300.8
40.	125.664	1256.6	⅛	148.048	1744.2	¼	170.431	2311.5
⅛	126.056	1264.5	¼	148.440	1753.5	⅜	170.824	2322.1
¼	126.449	1272.4	⅜	148.833	1762.7	½	171.217	2332.8
⅜	126.842	1280.3	½	149.226	1772.1	⅝	171.609	2343.5
½	127.235	1288.2	⅝	149.618	1781.4	¾	172.002	2354.3
⅝	127.627	1296.2	¾	150.011	1790.8	⅞	172.395	2365.0
¾	128.020	1304.2	⅞	150.404	1800.1	**55.**	172.788	2375.8
⅞	128.413	1312.2	**48.**	150.796	1809.6	⅛	173.180	2386.6
41.	128.805	1320.3	⅛	151.189	1819.0	¼	173.573	2397.5
⅛	129.198	1328.3	¼	151.582	1828.5	⅜	173.966	2408.3
¼	129.591	1336.4	⅜	151.975	1837.9	½	174.358	2419.2
⅜	129.983	1344.5	½	152.367	1847.5	⅝	174.751	2430.1
½	130.376	1352.7	⅝	152.760	1857.0	¾	175.144	2441.1
⅝	130.769	1360.8	¾	153.153	1866.5	⅞	175.536	2452.0
¾	131.161	1369.0	⅞	153.545	1876.1	**56.**	175.929	2463.0
⅞	131.554	1377.2	**49.**	153.938	1885.7	⅛	176.322	2474.0
42.	131.947	1385.4	⅛	154.331	1895.4	¼	176.715	2485.0
⅛	132.340	1393.7	¼	154.723	1905.0	⅜	177.107	2496.1
¼	132.732	1402.0	⅜	155.116	1914.7	½	177.500	2507.2
⅜	133.125	1410.3	½	155.509	1924.4	⅝	177.893	2518.3
½	133.518	1418.6	⅝	155.902	1934.2	¾	178.285	2529.4
⅝	133.910	1427.0	¾	156.294	1943.9	⅞	178.678	2540.6
¾	134.303	1435.4	⅞	156.687	1953.7	**57.**	179.071	2551.8
⅞	134.696	1443.8	**50.**	157.080	1963.5	⅛	179.463	2563.0
43.	135.088	1452.2	⅛	157.472	1973.3	¼	179.856	2574.2
⅛	135.481	1460.7	¼	157.865	1983.2	⅜	180.249	2585.4
¼	135.874	1469.1	⅜	158.258	1993.1	½	180.642	2596.7
⅜	136.267	1477.6	½	158.650	2003.0	⅝	181.034	2608.0
½	136.659	1486.2	⅝	159.043	2012.9	¾	181.427	2619.4
⅝	137.052	1494.7	¾	159.436	2022.8	⅞	181.820	2630.7
¾	137.445	1503.3	⅞	159.829	2032.8	**58.**	182.212	2642.1
⅞	137.837	1511.9	**51.**	160.221	2042.8	⅛	182.605	2653.5
44.	138.230	1520.5	⅛	160.614	2052.8	¼	182.998	2664.9
⅛	138.623	1529.2	¼	161.007	2062.9	⅜	183.390	2676.4
¼	139.015	1537.9	⅜	161.399	2073.0	½	183.783	2687.8
⅜	139.408	1546.6	½	161.792	2083.1	⅝	184.176	2699.3

Diam.	Circum.	Area	Diam.	Circum.	Area	Diam.	Circum.	Area
58. ¾	184.569	2710.9	**65.** ⅞	206.952	3408.2	**73.**	229.336	4185.4
⅞	184.961	2722.4	**66.**	207.345	3421.2	⅛	229.729	4199.7
59.	185.354	2734.0	⅛	207.738	3434.2	¼	230.122	4214.1
⅛	185.747	2745.6	¼	208.131	3447.2	⅜	230.514	4228.5
¼	186.139	2757.2	⅜	208.523	3460.2	½	230.907	4242.9
⅜	186.532	2768.8	½	208.916	3473.2	⅝	231.300	4257.4
½	186.925	2780.5	⅝	209.309	3486.3	¾	231.692	4271.8
⅝	187.317	2792.2	¾	209.701	3499.4	⅞	232.085	4286.3
¾	187.710	2803.9	⅞	210.094	3512.5	**74.**	232.478	4300.8
⅞	188.103	2815.7	**67.**	210.487	3525.7	⅛	232.871	4315.4
60.	188.496	2827.4	⅛	210.879	3538.8	¼	233.263	4329.9
⅛	188.888	2839.2	¼	211.272	3552.0	⅜	233.656	4344.5
¼	189.281	2851.0	⅜	211.665	3565.2	½	234.049	4359.2
⅜	189.674	2862.9	½	212.058	3578.5	⅝	234.441	4373.8
½	190.066	2874.8	⅝	212.450	3591.7	¾	234.834	4388.5
⅝	190.459	2886.6	¾	212.843	3605.0	⅞	235.227	4403.1
¾	190.852	2898.6	⅞	213.236	3618.3	**75.**	235.619	4417.9
⅞	191.244	2910.5	**68.**	213.628	3631.7	⅛	236.012	4432.6
61.	191.637	2922.5	⅛	214.021	3645.0	¼	236.405	4447.4
⅛	192.030	2934.5	¼	214.414	3658.4	⅜	236.798	4462.2
¼	192.423	2946.5	⅜	214.806	3671.8	½	237.190	4477.0
⅜	192.815	2958.5	½	215.199	3685.3	⅝	237.583	4491.8
½	193.208	2970.6	⅝	215.592	3698.7	¾	237.976	4506.7
⅝	193.601	2982.7	¾	215.984	3712.2	⅞	238.368	4521.5
¾	193.993	2994.8	⅞	216.377	3725.7	**76.**	238.761	4536.5
⅞	194.386	3006.9	**69.**	216.770	3739.3	⅛	239.154	4551.4
62.	194.779	3019.1	⅛	217.163	3752.8	¼	239.546	4566.4
⅛	195.171	3031.3	¼	217.555	3766.4	⅜	239.939	4581.3
¼	195.564	3043.5	⅜	217.948	3780.0	½	240.332	4596.3
⅜	195.957	3055.7	½	218.341	3793.7	⅝	240.725	4611.4
½	196.350	3068 0	⅝	218.733	3807.3	¾	241.117	4626.4
⅝	196.742	3080.3	¾	219.126	3821.0	⅞	241.510	4641.5
¾	197.135	3092.6	⅞	219.519	3834.7	**77.**	241.903	4656.6
⅞	197.528	3104.9	**70.**	219.911	3848.5	⅛	242.295	4671.8
63.	197.920	3117.2	⅛	220.304	3862.2	¼	242.688	4686.9
⅛	198.313	3129.6	¼	220.697	3876.0	⅜	243.081	4702.1
¼	198.706	3142.0	⅜	221.090	3889.8	½	243.473	4717.3
⅜	199.098	3154.5	½	221.482	3903.6	⅝	243.866	4732.5
½	199.491	3166.9	⅝	221.875	3917.5	¾	244.259	4747.8
⅝	199.884	3179.4	¾	222.268	3931.4	⅞	244.652	4763.1
¾	200.277	3191.9	⅞	222.660	3945.3	**78.**	245.044	4778.4
⅞	200.669	3204.4	**71.**	223.053	3959.2	⅛	245.437	4793.7
64.	201.062	3217.0	⅛	223.446	3973.1	¼	245.830	4809.0
⅛	201.455	3229.6	¼	223.838	3987.1	⅜	246.222	4824.4
¼	201.847	3242.2	⅜	224.231	4001.1	½	246.615	4839.8
⅜	202.240	3254.8	½	224.624	4015.2	⅝	247.008	4855.2
½	202.633	3267.5	⅝	225.017	4029.2	¾	247.400	4870.7
⅝	203.025	3280.1	¾	225.409	4043.3	⅞	247.793	4886.2
¾	203.418	3292.8	⅞	225.802	4057.4	**79.**	248.186	4901.7
⅞	203.811	3305.6	**72.**	226.195	4071.5	⅛	248.579	4917.2
65.	204.204	3318.3	⅛	226.587	4085.7	¼	248.971	4932.7
⅛	204.596	3331.1	¼	226.980	4099.8	⅜	249.364	4948.3
¼	204.989	3343.9	⅜	227.373	4114.0	½	249.757	4963.9
⅜	205.382	3356.7	½	227.765	4128.2	⅝	250.149	4979.5
½	205.774	3369.6	⅝	228.158	4142.5	¾	250.542	4995.2
⅝	206.167	3382.4	¾	228.551	4156.8	⅞	250.935	5010.9
¾	206.560	3395.3	⅞	228.944	4171.1	**80.**	251.327	5026.5

Diam.	Circum.	Area	Diam.	Circum.	Area	Diam.	Circum.	Area
80.			**87.**			**94.**		
⅛	251.720	5042.3	¼	274.104	5978.9	⅜	296.488	6995.3
¼	252.113	5058.0	⅜	274.497	5996.0	½	296.881	7013.4
⅜	252.506	5073.8	½	274.889	6013.2	⅝	297.273	7032.5
½	252.898	5089.6	⅝	275.282	6030.4	¾	297.666	7051.0
⅝	253.291	5105.4	¾	275.675	6047.6	⅞	298.059	7069.6
¾	253.684	5121.2	⅞	276.067	6064.9	**95.**	298.451	7088.2
⅞	254.076	5137.1	**88.**	276.460	6082.1	⅛	298.844	7106.9
81.	254.469	5153.0	⅛	276.853	6099.4	¼	299.237	7125.6
⅛	254.862	5168.9	¼	277.246	6116.7	⅜	299.629	7144.3
¼	255.254	5184.9	⅜	277.638	6134.1	½	300.022	7163.0
⅜	255.647	5200.8	½	278.031	6151.4	⅝	300.415	7181.8
½	256.040	5216.8	⅝	278.424	6168.8	¾	300.807	7200.6
⅝	256.433	5232.8	¾	278.816	6186.2	⅞	301.200	7219.4
¾	256.825	5248.9	⅞	279.209	6203.7	**96.**	301.593	7238.2
⅞	257.218	5264.9	**89.**	279.602	6221.1	⅛	301.986	7257.1
82	257.611	5281.0	⅛	279.994	6238.6	¼	302.378	7276.0
⅛	258.003	5297.1	¼	280.387	6256.1	⅜	302.771	7294.9
¼	258.396	5313.3	⅜	280.780	6273.7	½	303.164	7313.8
⅜	258.789	5329.4	½	281.173	6291.2	⅝	303.556	7332.8
½	259.181	5345.6	⅝	281.565	6308.8	¾	303.949	7351.8
⅝	259.574	5361.8	¾	281.958	6326.4	⅞	304.342	7370.8
¾	259.967	5378.1	⅞	282.351	6344.1	**97.**	304.734	7389.8
⅞	260.359	5394.3	**90.**	282.743	6361.7	⅛	305.127	7408.9
83.	260.752	5410.6	⅛	283.136	6379.4	¼	305.520	7428.0
⅛	261.145	5426.9	¼	283.529	6397.1	⅜	305.913	7447.1
¼	261.538	5443.3	⅜	283.921	6414.9	½	306.305	7466.2
⅜	261.930	5459.6	½	284.314	6432.6	⅝	306.698	7485.3
½	262.323	5476.0	⅝	284.707	6450.4	¾	307.091	7504.5
⅝	262.716	5492.4	¾	285.100	6468.2	⅞	307.483	7523.7
¾	263.108	5508.8	⅞	285.492	6486.0	**98.**	307.876	7543.0
⅞	263.501	5525.3	**91.**	285.885	6503.9	⅛	308.269	7562.2
84.	263.894	5541.8	⅛	286.278	6521.8	¼	308.661	7581.5
⅛	264.286	5558.3	¼	286.670	6539.7	⅜	309.054	7600.8
¼	264.679	5574.8	⅜	287.063	6567.6	½	309.447	7620.1
⅜	265.072	5591.4	½	287.456	6575.5	⅝	309.840	7639.5
½	265.465	5607.9	⅝	287.848	6593.5	¾	310.232	7658.9
⅝	265.857	5624.5	¾	288.241	6611.5	⅞	310.625	7678.3
¾	266.250	5641.2	⅞	288.634	6629.6	**99.**	311.018	7697.7
⅞	266.643	5657.8	**92.**	289.027	6647.6	⅛	311.410	7717.1
85.	267.035	5674.5	⅛	289.419	6665.7	¼	311.803	7736.6
⅛	267.428	5691.2	¼	289.812	6683.8	⅜	312.196	7756.1
¼	267.821	5707.9	⅜	290.205	6701.9	½	312.588	7775.6
⅜	268.213	5724.7	½	290.597	6720.1	⅝	312.981	7795.2
½	268.606	5741.5	⅝	290.990	6738.2	¾	313.374	7814.8
⅝	268.999	5758.3	¾	291.383	6756.4	⅞	313.767	7834.4
¾	269.392	5775.1	⅞	291.775	6774.7	**100.**	314.159	7854.0
⅞	269.784	5791.9	**93.**	292.168	6792.9			
86.	270.177	5808.8	⅛	292.561	6811.2			
⅛	270.570	5825.7	¼	292.954	6829.5			
¼	270.962	5842.6	⅜	293.346	6847.8			
⅜	271.355	5859.6	½	293.739	6866.1			
½	271.748	5876.5	⅝	294.132	6884.5			
⅝	272.140	5893.5	¾	294.524	6902.9			
¾	272.533	5910.6	⅞	294.917	6921.3			
⅞	272.926	5927.6	**94.**	295.310	6939.8			
87.	273.319	5944.7	⅛	295.702	6958.2			
⅛	273.711	5961.8	¼	296.095	6976.7			

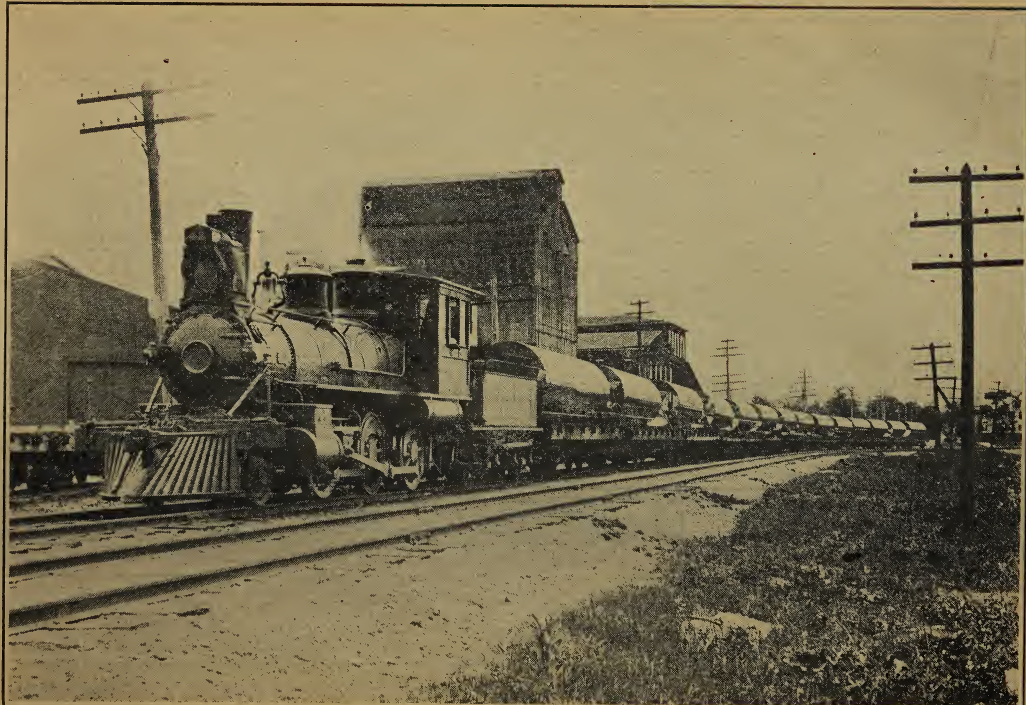

Fig. 76—ONE OF MANY TRAIN-LOAD SHIPMENTS OF LOCK-BAR PIPE

Lengths of the Arcs of Circles to the Radius 1.

Degrees						Minutes		Seconds	
0	0.00000 00000	60	1.04719 75512	120	2.09439 51024	0	0.00000 00000	0	0.00000 00000
1	0.01745 32925	61	1.06465 08437	121	2.11184 83949	1	0.00029 08882	1	0.00000 48481
2	0.03490 65850	62	1.08210 41362	122	2.12930 16874	2	0.00058 17764	2	0.00000 96963
3	0.05235 98776	63	1.09955 74288	123	2.14675 49800	3	0.00087 26646	3	0.00001 45444
4	0.06981 31701	64	1.11701 07213	124	2.16420 82725	4	0.00116 35528	4	0.00001 93925
5	0.08726 64626	65	1.13446 40138	125	2.18166 15650	5	0.00145 44410	5	0.00002 42407
6	0.10471 97551	66	1.15191 73063	126	2.19911 48575	6	0.00174 53293	6	0.00002 90888
7	0.12217 30476	67	1.16937 05988	127	2.21656 81500	7	0.00203 62175	7	0.00003 39370
8	0.13962 63402	68	1.18682 38914	128	2.23402 14426	8	0.00232 71057	8	0.00003 87851
9	0.15707 96327	69	1.20427 71839	129	2.25147 47351	9	0.00261 79939	9	0.00004 36332
10	0.17453 29252	70	1.22173 04764	130	2.26892 80276	10	0.00290 88821	10	0.00004 84814
11	0.19198 62177	71	1.23918 37689	131	2.28638 13201	11	0.00319 97703	11	0.00005 33295
12	0.20943 95102	72	1.25663 70614	132	2.30383 46126	12	0.00349 06585	12	0.00005 81776
13	0.22689 28028	73	1.27409 03540	133	2.32128 79052	13	0.00378 15467	13	0.00006 30258
14	0.24434 60953	74	1.29154 36465	134	2.33874 11977	14	0.00407 24349	14	0.00006 78739
15	0.26179 93878	75	1.30899 69390	135	2.35619 44902	15	0.00436 33231	15	0.00007 27221
16	0.27925 26803	76	1.32645 02315	136	2.37364 77827	16	0.00465 42113	16	0.00007 75702
17	0.29670 59728	77	1.34390 35240	137	2.39110 10752	17	0.00494 50995	17	0.00008 24183
18	0.31415 92654	78	1.36135 68166	138	2.40855 43678	18	0.00523 59878	18	0.00008 72665
19	0 33161 25579	79	1.37881 01091	139	2.42600 76603	19	0.00552 68760	19	0.00009 21146
20	0.34906 58504	80	1.39626 34016	140	2.44346 09528	20	0.00581 77642	20	0.00009 69627
21	0.36651 91429	81	1.41371 66941	141	2.46091 42453	21	0.00610 86524	21	0.00010 18109
22	0.38397 24354	82	1.43116 99866	142	2.47836 75378	22	0.00639 95406	22	0.00010 66590
23	0.40142 57280	83	1.44862 32792	143	2.49582 08304	23	0.00669 04288	23	0.00011 15071
24	0.41887 90205	84	1.46607 65717	144	2.51328 41229	24	0.00698 13170	24	0.00011 63553
25	0.43633 23130	85	1.48352 98642	145	2.53072 74154	25	0.00727 22052	25	0.00012 12034
26	0.45378 56055	86	1.50098 31567	146	2.54818 07079	26	0.00756 30934	26	0.00012 60516
27	0.47123 88980	87	1.51843 64492	147	2.56563 40004	27	0.00785 39816	27	0.00013 08997
28	0.48869 21906	88	1.53588 97418	148	2.58308 72930	28	0.00814 48698	28	0.00013 57478
29	0.50614 54831	89	1.55334 30343	149	2.60054 05855	29	0.00843 57581	29	0.00014 05960
30	0.52359 87756	90	1.57079 63268	150	2.61799 38780	30	0.00872 66463	30	0.00014 54441
31	0.54105 20681	91	1.58824 96193	151	2.63544 71705	31	0.00901 75345	31	0.00015 02922
32	0.55850 53606	92	1.60570 29118	152	2.65290 04630	32	0.00930 84227	32	0.00015 51404
33	0.57595 86532	93	1.62315 62044	153	2.67035 37556	33	0.00959 93109	33	0.00015 99885
34	0.59341 19457	94	1.64060 94969	154	2.68780 70481	34	0.00989 01991	34	0.00016 48367
35	0.61086 52382	95	1.65806 27894	155	2.70526 03406	35	0.01018 10873	35	0.00016 96848
36	0.62831 85307	96	1.67551 60819	156	2.72271 36331	36	0.01047 19755	36	0.00017 45329
37	0.64577 18232	97	1.69296 93744	157	2.74016 69256	37	0.01076 28637	37	0.00017 93811
38	0.66322 51158	98	1.71042 26670	158	2.75762 02182	38	0.01105 37519	38	0.00018 42292
39	0.68067 84083	99	1.72787 59595	159	2.77507 35107	39	0.01134 46401	39	0.00018 90773
40	0.69813 17008	100	1.74532 92520	160	2.79252 68032	40	0.01163 55283	40	0.00019 39255
41	0.71558 49933	101	1.76278 25445	161	2.80998 00957	41	0.01192 64166	41	0.00019 87736
42	0.73303 82858	102	1.78023 58370	162	2.82743 33882	42	0.01221 73048	42	0.00020 36217
43	0.75049 15784	103	1.79768 91296	163	2.84488 66808	43	0.01250 81930	43	0.00020 84699
44	0.76794 48709	104	1.81514 24221	164	2.86233 99733	44	0.01279 90812	44	0.00021 33180
45	0.78539 81634	105	1.83259 57146	165	2.87979 32658	45	0.01308 99694	45	0.00021 81662
46	0.80285 14559	106	1.85004 90071	166	2.89724 65583	46	0.01338 08576	46	0.00022 30143
47	0.82030 47484	107	1.86750 22996	167	2.91469 98508	47	0.01367 17458	47	0.00022 78624
48	0.83775 80410	108	1.88495 55922	168	2.93215 31434	48	0.01396 26340	48	0.00023 27106
49	0.85521 13335	109	1.90240 88847	169	2.94960 64359	49	0.01425 35222	49	0.00023 75587
50	0.87266 46260	110	1.91986 21772	170	2.96705 97284	50	0.01454 44104	50	0.00024 24068
51	0.89011 79185	111	1.93731 54697	171	2.98451 30209	51	0.01483 52986	51	0.00024 72550
52	0.90757 12110	112	1.95476 87622	172	3.00196 63134	52	0.01512 61869	52	0.00025 21031
53	0.92502 45036	113	1.97222 20548	173	3.01941 96060	53	0.01541 70751	53	0.00025 69513
54	0.94247 77961	114	1.98967 53473	174	3.03687 28985	54	0.01570 79633	54	0.00026 17994
55	0.95993 10886	115	2.00712 86398	175	3.05432 61910	55	0.01599 88515	55	0.00026 66475
56	0.97738 43811	116	2.02458 19323	176	3.07177 94835	56	0.01628 97397	56	0.00027 14958
57	0.99483 76736	117	2.04203 52248	177	3.08923 27760	57	0.01658 06279	57	0.00027 63437
58	1.01229 09662	118	2.05948 85174	178	3.10668 60685	58	0.01687 15161	58	0.00028 11919
59	1.02974 42587	119	2.07694 18099	179	3.12413 93611	59	0.01716 24043	59	0.00028 60401
60	1.04719 75512	120	2.09439 51024	180	3.14159 26536	60	0.01745 32925	60	0.00029 08882

LENGTH CORRECTION FOR 100.00 FT.

FROM 0 TO 5.9 RISE

Rise	Angle	Cor.	Rise	Angle	Cor.	Rise	Angle	Cor.
.0			2.0	1°-09′	.02014	4.0	2°-18′	.08056
.1			2.1	1°-13′	.02255	4.1	2°-21′	.08410
.2			2.2	1°-16′	.02444	4.2	2°-25′	.08894
.3	0°-11′	.00051	2.3	1°-20′	.02708	4.3	2°-28′	.09266
.4	0°-14′	.00083	2.4	1°-23′	.02914	4.4	2°-32′	.09773
.5	0°-18′	.00137	2.5	1°-26′	.03129	4.5	2°-35′	.10163
.6	0°-21′	.00187	2.6	1°-30′	.03427	4.6	2°-39′	.10694
.7	0°-25′	.00264	2.7	1°-33′	.03659	4.7	2°-42′	.11101
.8	0°-28′	.00332	2.8	1°-37′	.03980	4.8	2°-46′	.11656
.9	0°-31′	.00407	2.9	1°-40′	.04231	4.9	2°-49′	.12081
1.0	0°-35′	.00518	3.0	1°-44′	.04576	5.0	2°-52′	.12514
1.1	0°-38′	.00611	3.1	1°-47′	.04843	5.1	2°-56′	.13102
1.2	0°-42′	.00746	3.2	1°-50′	.05119	5.2	2°-59′	.13553
1.3	0°-45′	.00857	3.3	1°-54′	.05498	5.3	3°-03′	.14165
1.4	0°-49′	.01016	3.4	1°-57′	.05791	5.4	3°-06′	.14633
1.5	0°-52′	.01144	3.5	2°-01′	.06194	5.5	3°-09′	.15109
1.6	0°-55′	.01280	3.6	2°-04′	.06505	5.6	3°-12′	.15592
1.7	0°-59′	.01473	3.7	2°-08′	.06931	5.7	3°-16′	.16249
1.8	1°-02′	.01626	3.8	2°-11′	.07260	5.8	3°-20′	.16918
1.9	1°-06′	.01843	3.9	2°-15′	.07716	5.9	3°-23′	.17430

FROM 6.0 TO 11.9 RISE

Rise	Angle	Cor.	Rise	Angle	Cor.	Rise	Angle	Cor.
6.0	3°-27′	.18123	8.0	4°-35′	.32085	10.0	5°-43′	.49982
6.1	3°-30′	.18652	8.1	4°-38′	.32786	10.1	5°-47′	.51159
6.2	3°-33′	.19189	8.2	4°-42′	.33739	10.2	5°-50′	.52052
6.3	3°-36′	.19733	8.3	4°-45′	.34463	10.3	5°-53′	.52952
6.4	3°-40′	.20470	8.4	4°-49′	.35442	10.4	5°-57′	.54165
6.5	3°-44′	.21221	8.5	4°-52′	.36182	10.5	6°-00′	.55083
6.6	3°-47′	.21793	8.6	4°-55′	.36932	10.6	6°-04′	.56319
6.7	3°-50′	.22373	8.7	4°-59′	.37943	10.7	6°-07′	.57256
6.8	3°-54′	.23157	8.8	5°-02′	.38711	10.8	6°-10′	.58201
6.9	3°-57′	.23812	8.9	5°-06′	.39746	10.9	6°-14′	.59472
7.0	4°-01′	.24563	9.0	5°-09′	.40532	11.0	6°-17′	.60435
7.1	4°-04′	.25178	9.1	5°-12′	.41325	11.1	6°-21′	.61731
7.2	4°-07′	.25801	9.2	5°-16′	.42396	11.2	6°-24′	.62712
7.3	4°-11′	.26643	9.3	5°-19′	.43207	11.3	6°-27′	.63700
7.4	4°-14′	.27283	9.4	5°-23′	.44303	11.4	6°-31′	.65031
7.5	4°-18′	.28149	9.5	5°-26′	.45133	11.5	6°-34′	.66038
7.6	4°-21′	.28807	9.6	5°-29′	.45970	11.6	6°-38′	.67394
7.7	4°-25′	.29696	9.7	5°-33′	.47098	11.7	6°-41′	.68419
7.8	4°-28′	.30372	9.8	5°-36′	.47955	11.8	6°-44′	.69453
7.9	4°-32′	.31383	9.9	5°-40′	.49107	11.9	6°-48′	.70843

Conversion Table

Basis: I cubic foot of water at 39.1°F. = 62.425 pounds.
1 U. S. gallon = 231 cubic inches.
1 imperial gallon = 277.274 cubic inches.*

U. S. gallon	=	231.000000 cubic inches.
U. S. gallon	=	0.133681 cubic foot.
U. S. gallon	=	0.833111 imperial gallon.
U. S. gallon	=	3.785434 liters.
U. S. gallon of water at 39.1°F	=	8.345009 pounds.
Imperial gallon	=	277.274000 cubic inches.
Imperial gallon	=	0.160459 cubic foot.
Imperial gallon	=	1.200320 U. S. gallons.
Imperial gallon	=	4.543734 liters.
Imperial gallon of water at 39.1°F	=	10.016684 pounds.*
Cubic foot	=	7.480519 U. S. gallons.
Cubic foot	=	6.232103 imperial gallons.
Cubic foot	=	28.317016 liters.
Cubic foot of water at 39.1°F	=	62.425000 pounds.
Cubic foot of water at 39.1°F	=	0.031212 ton.
Cubic inch	=	0.004329 U. S. gallon.
Cubic inch	=	0.003607 imperial gallon.
Cubic inch	=	0.016387 liter.
Cubic inch of water at 39.1°F	=	0.036126 pound.
Cubic inch of water at 39.1°F	=	0.578009 ounce.
Pound of water at 39.1°F	=	27.681217 cubic inches.
Pound of water at 39.1°F	=	0.016019 cubic foot.
Pound of water at 39.1°F	=	0.119832 U. S. gallon.
Pound of water at 39.1°F	=	0.099833 imperial gallon.
Pound of water at 39.1°F	=	0.453617 liter.
Liter	=	0.264170 U. S. gallon.
Liter	=	0.220083 imperial gallon.
Liter	=	61.023378 cubic inches.
Liter	=	0.035314 cubic foot.
Liter of water at 39.1°F	=	2.204505 pounds.

*The British imperial gallon is usually defined as being equal to 277.274 cubic inches, or 10 pounds of pure water at the temperature of 62°F. when the barometer is at 30 inches.

CONVENIENT EQUIVALENTS

1 second-foot equals 40 California miner's inches. (Law of March 23, 1901.)

1 second-foot equals 38.4 Colorado miner's inches.

1 second-foot equals 7.48 United States gallons per second; equals 448.8 gallons per mintue; equals 646 317 gallons per day.

1 second-foot equals 6.23 British imperial gallons per second.

1 second-foot for one year covers one square mile 1,131 feet deep; 13.57 inches deep.

1 second-foot for one year equals 31 536 000 cubic feet.

1 second-foot equals about one acre-inch per hour.

1 second-foot falling 10 feet equals 1.136 horse-power.

100 California miner's inches equal 18.7 United States gallons per second.

100 California miner's inches equal 96.0 Colorado miner's inches.

100 California miner's inches for one day equal 4.96 acre-feet.

100 Colorado miner's inches equal 2.60 second-feet.

100 Colorado miner's inches equal 19.5 United States gallons per second.

100 Colorado miner's inches equal 104 California miner's inches.

100 Colorado miner's inches for one day equal 5.17 acre-feet.

100 United States gallons per minute equal 0.223 second-foot.

100 United States gallons per minute for one day equal 0.442 acre-foot.

1 000 000 United States gallons per day equal 1.55 second-feet.

1 000 000 United States gallons equal 3.07 acre-feet.

1 000 000 cubic feet equal 22.96 acre-feet.

1 acre-foot equals 325 851 gallons.

1 inch deep on 1 square mile equals 2 323 200 cubic feet.

1 inch deep on 1 square mile equals .0737 second-foot per year.

Fig. 77—66″ LOCK-BAR PIPE LINE—BROOKLYN, N. Y. THROUGH CITY STREETS

Weights of Steel Plates

Per Square Foot

U. S. Standard July 1, 1893	American	English	Decimals	Inches	Steel
	Brown & Sharpe	Stubbs or Birmingham			
			$.187^{5}$	3/16	7.655
7			.188		
6		6	.203		8.288
			$.203^{125}$	13/64	8.293
	4		$.204^{31}$		8.342
			$.218^{75}$	7/32	8.931
5			.219		
		5	.22		8.982
	3		$.229^{42}$		9.367
4			.234		
			$.234^{375}$	15/64	9.569
		4	.238		9.717
			$.244^{918}$		10.000
3			.250	1/4	10.207
	2		$.257^{63}$		10.519
		3	.259		10.575
			$.265^{625}$	17/64	10.845
2			.266		
1			.281		
			$.281^{25}$	9/32	11.483
		2	.284		11.595
	1		$.289^{3}$		11.812
			$.296^{875}$	19/64	12.121
		1	.300		12.249
			$.312^{5}$	5/16	12.759
0			.313		
	0		$.324^{86}$		13.264
			$.328^{125}$	21/64	13.397
		0	.34		13.882
			$.343^{75}$	11/32	14.035
00			.344		
			$.359^{375}$	23/64	14.673
	00		$.364^{8}$		14.894
			$.367^{3}$		14.996
000			.375	3/8	15.311
		00	.38		15.515
			$.390^{625}$	25/64	15.949
0000			.406		
			$.406^{25}$	13/32	16.587
	000		$.409^{64}$		16.725

Weights of Steel Plates—Continued

Per Square Foot

U. S. Standard July 1, 1893	American Brown & Sharpe	English Stubbs or Birmingham	Decimals	Inches	Steel
			$.421^{875}$	27/64	17.225
		000	.425		17.352
00000			$.437^{5}$	7/16	17.863
			.438		
			$.453^{125}$	29/64	18.501
		0000	.454		18.536
	0000		.46		18.781
000000			$.468^{75}$	15/32	19.139
			.469		
			$.484^{375}$	31/64	19.777
0000000		00000	.500	1/2	20.415
			$.515^{625}$	33/64	21.053
			$.531^{25}$	17/32	21.691
			$.546^{875}$	35/64	22.329
			$.562^{5}$	9/16	22.966
			$.578^{125}$	37/64	23.604
			$.593^{75}$	19/32	24.242
			$.609^{375}$	39/64	24.880
			.625	5/8	25.518
			$.640^{625}$	41/64	26.156
			$.656^{25}$	21/32	26.794
			$.671^{875}$	43/64	27.432
			$.687^{5}$	11/16	28.070
			$.703^{125}$	45/64	28.708
			$.718^{75}$	23/32	29.346
			$.734^{375}$	47/64	29.984
			.750	3/4	30.622
			$.765^{625}$	49/64	31.260
			$.781^{25}$	25/32	31.898
			$.796^{875}$	51/64	32.536
			$.812^{5}$	13/16	33.174
			$.828^{125}$	53/64	33.812
			$.843^{75}$	27/32	34.450
			$.859^{375}$	55/64	35.088
			.875	7/8	35.726
			$.890^{625}$	57/64	36.364
			$.906^{25}$	29/32	37.002

Weights of Steel Plates—Continued

Per Square Foot

Decimals	Inches	Steel	Decimals	Inches	Steel
$.921^{875}$	59/64	37.640	1.218^{75}	1.7/32	49.761
$.937^{5}$	15/16	38.278	1.234^{37}	1.15/64	50.399
$.953^{125}$	61/64	38.916	1.25	1.1/4	51.037
$.968^{75}$	31/32	39.554	1.281^{25}	1.9/32	52.313
$.984^{375}$	63/64	40.192	1.312^{5}	1.5/16	53.589
1.	1.	40.83	1.343^{75}	1.11/32	54.865
1.015^{62}	1.1/64	41.467	1.375	1.3/8	56.141
1.031^{25}	1.1/32	42.106	1.406^{25}	1.13/32	57.417
1.046^{87}	1.3/64	42.744	1.437^{5}	1.7/16	58.693
1.062^{5}	1.1/16	43.381	1.468^{75}	1.15/32	59.969
1.078^{12}	1.5/64	44.019	1.5	1.1/2	61.245
1.093^{75}	1.3/32	44.657	1.531^{25}	1.17/32	62.521
1.109^{37}	1.7/64	45.295	1.562^{5}	1.9/16	63.796
1.125	1.1/8	45.933	1.593^{75}	1.19/32	65.072
1.140^{62}	1.9/64	46.571	1.625	1.5/8	66.348
1.156^{25}	1.5/32	47.209	1.656^{25}	1.21/32	67.624
1.171^{87}	1.11/64	47.847	1.687^{5}	1.11/16	68.900
1.187^{5}	1.3/16	48.485	1.718^{75}	1.23/32	70.176
1.203^{12}	1.13/64	49.123	1.75	1.3/4	71.452

Note.—This table is based upon the average weight of 1 cubic foot of Steel, as given by—

Haswell, ... **490.12**
Nystrom, ... **489.80**

In calculating total weights of Plates, a percentage must be added to the weight given in this table to allow for spring of Rolls, according to width and gauge of Plates. See Standard Specifications, table of allowance for overweight, pages 26 and 27.

WEIGHTS OF STEEL ANGLES

Size in Inches	Thickness in Inches														
	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1
8 x8	....	....	....	....	....	....	26.4	29.6	32.7	35.8	38.9	42.0	45.0	48.1	51.0
7 x3½	....	....	....	....	....	15.0	17.0	19.1	21.0	23.0	24.9	26.8	28.7	30.5	32.3
6 x6	....	....	....	....	14.9	17.2	19.6	21.9	24.2	26.5	28.7	31.0	33.1	35.3	37.4
6 x4	....	....	....	....	12.3	14.3	16.2	18.1	20.0	21.8	23.6	25.4	27.2	28.9	30.6
6 x3½	....	....	....	....	11.7	13.5	15.3	17.1	18.9	20.6	22.4	24.0	25.7	27.3	28.9
5 x5	....	....	....	....	12.3	14.3	16.2	18.1	20.0	21.8	23.6	25.4	27.2	28.9	30.6
5 x4	....	....	....	....	11.0	12.8	14.5	16.2	17.8	19.5	21.1	22.7	24.2	....	....
5 x3½	....	....	....	8.7	10.4	12.0	13.6	15.2	16.8	18.3	19.8	21.3	22.7	....	....
5 x3	....	....	....	8.2	9.8	11.3	12.8	14.3	15.7	17.1	18.5	19.9	....	....	....
4½x3	....	....	....	7.7	9.1	10.6	11.9	13.3	14.7	16.0	17.3	18.5	....	....	....
4 x4	....	5.2	6.6	8.2	9.8	11.3	12.8	14.3	15.7	17.1	18.5	19.9	....	....	....
4 x3½	....	....	....	7.7	9.1	10.6	11.9	13.3	14.7	16.0	17.3	....	....	....	....
4 x3	....	....	....	7.2	8.5	9.8	11.1	12.4	13.6	14.8	16.0	17.1	....	....	....
3½x3½	....	....	5.8	7.2	8.5	9.8	11.1	12.4	13.6	14.8	16.0	17.1	....	....	....
3½ 3	....	....	....	6.6	7.9	9.1	10.2	11.4	12.5	13.6	14.7	15.8	....	....	....
3½x2½	....	....	4.9	6.1	7.2	8.3	9.4	10.4	11.5	12.5	....	....	....	....	....
3¼x3¼	....	....	....	....	7.85	....	....	....	....	....	....	....	....	....	....
3¼x2	....	....	4.3	5.3	6.3	7.2	8.1	9.0	....	....	....	....	....	....	....
3 x3	2.5	3.7	4.9	6.1	7.2	8.3	9.4	10.4	11.5	....	....	....	....	....	....
3 x2½	....	3.4	4.5	5.6	6.6	7.6	8.5	9.5	....	....	....	....	....	....	....
3 x2	....	3.1	4.1	5.0	5.9	6.8	7.7	....	....	....	....	....	....	....	....
2¾x2¾	2.3	3.4	4.5	5.6	6.6	7.6	8.5	....	....	....	....	....	....	....	....
2½x2½	2.1	3.1	4.1	5.0	5.9	6.8	7.7	....	....	....	....	....	....	....	....
2½x2	....	2.8	3.7	4.5	5.3	6.1	6.8	....	....	....	....	....	....	....	....
2½x1¾	....	2.6	3.4	....	....	....	....	....	....	....	....	....	....	....	....
2½x1½	....	2.4	3.2	3.9	....	....	....	....	....	....	....	....	....	....	....
2¼x2¼	1.9	2.8	3.7	4.5	5.3	6.1	6.8	....	....	....	....	....	....	....	....
2¼x1½	....	2.3	3.0	3.7	4.4	5.0	5.6	....	....	....	....	....	....	....	....
2 x2	1.7	2.5	3.2	4.0	4.7	5.3	....	....	....	....	....	....	....	....	....
2 x1½	....	2.1	2.8	3.4	4.0	....	....	....	....	....	....	....	....	....	....
2 x1⅜	....	2.1	2.7	....	....	....	....	....	....	....	....	....	....	....	....
1¾x1¾	1.4	2.2	2.8	3.4	4.0	4.6	....	....	....	....	....	....	....	....	....
1½x1½	1.3	1.8	2.4	2.9	3.4	....	....	....	....	....	....	....	....	....	....
1⅜x1	1.0	....	1.9	....	....	....	....	....	....	....	....	....	....	....	....
1⅜x ⅛	0.9	1.3	....	....	....	....	....	....	....	....	....	....	....	....	....
1¼x1¼	1.1	1.48	2.0	2.4	....	....	....	....	....	....	....	....	....	....	....
1⅛x1⅛	0.9	1.3	....	....	....	....	....	....	....	....	....	....	....	....	....
1 x1	0.8	1.2	1.5	....	....	....	....	....	....	....	....	....	....	....	....
1 x ¾	0.7	1.0	....	....	....	....	....	....	....	....	....	....	....	....	....
1 x ⅝	0.6	0.9	....	....	....	....	....	....	....	....	....	....	....	....	....
⅞x ⅞	0.7	1.0	....	....	....	....	....	....	....	....	....	....	....	....	....
¾x ¾	0.6	0.9	....	....	....	....	....	....	....	....	....	....	....	....	....
⅝x ⅝	0.5	....	....	....	....	....	....	....	....	....	....	....	....	....	....

The above weights are given in pounds per foot

CONE-HEAD BOILER RIVETS OF SCANT DIAMETER

L'gth Inches	½	9/16	⅝	11/16	¾	13/16	⅞	1	1⅛*	1¼*
¾	8.75	13.7	16.20	......	......	......	......	......	......	.....
⅞	9.35	14.4	17.22	......	......	......	......	......	......	.....
1	10.00	15.2	18.25	21.70	26.55	37.0	46	60	......	.....
1⅛	10.70	16.0	19.28	23.10	28.00	38.6	48	63	95	.....
1¼	11.40	16.8	20.31	24.50	29.45	40.2	50	65	98	133
1⅜	12.10	17.6	21.34	25.90	30.90	41.9	52	67	101	137
1½	12.80	18.4	22.37	27.30	32.35	43.5	54	69	104	141
1⅝	13.50	19.2	23.40	28.70	33.80	45.2	56	71	107	145
1¾	14.20	20.0	24.43	30.10	35.25					
1⅞	14.90	20.8	25.46	31.50	36.70					
2	15.60	21.6	26.49	32.90	38.15	47.	58	74	110	149
2⅛	16.30	22.4	27.52	34.30	39.60	48.7	60	77	114	153
2¼	17.00	23.2	28.55	35.70	41.05	50.3	62	80	118	157
2⅜	17.70	24.0	29.58	37.10	42.50	51.9	64	83	121	161
2½	18.40	24.8	30.61	38.50	43.95	53.5	66	86	124	165
2⅝	19.10	25.6	31.64	39.90	45.40	55.1	68	89	127	169
2¾	19.80	26.4	32.67	41.30	46.85	56.8	70	92	130	173
2⅞	20.50	27.2	33.70	42.70	48.30	58.4	72	95	133	177
3	21.20	28.0	34.73	44.10	49.75	60.	74	98	137	181
3¼	22.60	29.7	36.79	46.90	52.65	63.3	78	103	144	189
3½	24.00	31.5	38.85	49.70	55.55	66.5	82	108	151	197
3¾	25.40	33.3	40.91	52.50	58.45	69.8	86	113	158	205
4	26.80	35.2	42.97	55.30	61.35	73.	90	118	165	213
4¼	28.20	36.9	45.00	58.10	64.25	76.3	94	124	172	221
4½	29.60	38.6	47.09	60.90	67.15	79.5	98	130	179	229
4¾	31.00	40.3	49.15	63.70	70.05	82.8	102	136	186	237
5	32.40	42.0	51.21	66.50	72.95	86.	106	142	193	245
5¼	33.80	43.7	53.27	69.20	75.85	89.3	110	148	200	254
5½	35.20	45.4	55.33	72.00	78.75	92.5	114	154	206	263
5¾	36.60	47.1	57.39	74.80	81.65	95.7	118	160	212	272
6	38.00	48.8	59.45	77.60	84.55	99.	122	166	218	281
6½	40.80	52.0	63.57	83.30	90.35	105.5	130	177	231	297
7	43.60	55.2	67.69	88.90	96.15	112.	138	188	245	314
Heads.	5.50	8.40	11.50	13.20	18.00	23.0	29.0	38.0	56.0	77.5

*These two sizes are calculated for exact diameter.

Rivets with Button-Heads weigh approximately the same as Cone-Head Rivets.

Steeple.

Round.

Cone.

Countersunk

The measure of Countersunk Head Rivets is over all. All other styles are measured from under the head. Boiler Rivets less than one inch long are one-half cent per pound extra. Tank Rivets $\frac{7}{16}$ inch in diameter and less are sold at a list price and subject to discount.

Metric Conversion Table

Arranged by C. W. Hunt, New York.

Millimeters × .03937 = inches.
Millimeters ÷ 25.4 = inches.
Centimeters × .393 = inches.
Centimeters ÷ 2.54 = inches.
Meters × 39.37 = in. (Act Cong.)
Meters × 3.28 = feet.
Meters × 1.094 = yards.
Kilometers × .621 = miles.
Kilometres ÷ 1.6093 = miles.
Kilometers × 3280.7 = feet.
Sq. Millimeters × .055 = sq. in.
Sq. Millimeters ÷ 645 = sq. in.
Sq. Centimeters × .155 = sq. in.
Sq. Centimeters ÷ 6.45 = sq. in.
Sq. Meters × 10.764 = sq. ft.
Sq. Kilometers × 247.1 = acres.
Hectars × 2.47 = acres.
Cu. Centimeters ÷ 16.387 = cu. in.
Cu. Centimeters ÷ 3.69 = fl. drs. (U. S. P.)
Cu. Centimeters ÷ 29.57 = fl. ozs. (U. S. P.)
Cu. Meters × 35.314 = cu. ft.
Cu. Meters × 1.308 = cu. yds.
Cu. Meters × 264.2 = gals. (231 cubic inches.)
Litres × 61.023 = cu. in. (Act Cong.)
Litres × 33.84 = fl. oz. (U. S. P.)
Litres × 2642 = gals. (231 cu. in.)
Litres ÷ 3.78 = gals. (231 cu. in.)
Litres ÷ 28.317 = cubic feet.
Hectolitres × 3.53 = cubic feet.
Hectolitres ÷ 2.84 = bu. (2150.42 cu. inches.)
Hectolitres × .131 = cu, yds.
Hectolitres ÷ 26.42 = gals. (231 cubic inches.)
Grammes × 15.432 = grains (Act Congress.)
Grammes ÷ 981 = dynes.
Grammes (water) ÷ 29.57 = fl. oz
Grammes ÷ 28.35 = oz. av'pois.
Grammes per cu. cent ÷ 27.7 = lbs. per cu. in.
Joule × .7373 = ft. pounds.
Kilo-grammes × 2.2046 = lbs.
Kilo-grammes × 35.3 = oz. avoirdupois.
Kilo-grammes ÷ 1102.3 = tons. (2,000 lbs.)
Kilo-grammes per sq. cent. × 14.223 = lbs. per sq. in.
Kilo-gram metres × 7.233 = ft. lbs.
Kilo per metre × .672 = lbs. per foot.
Kilo per cubic metre × .026 = lbs. per cubic foot.
Kilo per Cheval × 2.235 = lbs. per horsepower.
Kilo-Watts × 1.35 = H. P.
Watts ÷ 746 = Horse Power.
Watts ÷ 737 = ft. lbs. per second.
Calorie × 3.968 = B. T. U.
Cheval vapeur × 98.3 = H. P.
(Centigrade) × 18 + 32 = deg. F.
Franc × 193 = dollars.
Gravity Paris = 980.94 centimeters per second.

Inches	×	0.08333	=feet
Inches	×	0.02778	=yards
Inches	×	0.00001578	=miles
Square inches	×	0.00695	=square feet
Square inches	×	0.0007716	=square yards
Cubic inches	×	0.00058	=cubic feet
Cubic inches	×	0.0000214	=cubic yards
Cubic inches	×	0.004329	=U. S. gallons
Feet	×	0.334	=yards
Feet	×	0.00019	=miles
Square feet	×	144.00	=square inches.
Square feet	×	0.1112	=square yards
Cubic feet	×	1728.00	=cubic inches
Cubic feet	×	0.03704	=cubic yards
Cubic feet	×	7.48	=U. S. gallons
Yards	×	36.000	=inches
Yards	×	3.000	=feet
Yards	×	0.0005681	=miles
Square yards	×	1296.000	=square inches
Square yards	×	9.000	=square feet
Cubic yards	×	46656.000	=cubic inches
Cubic yards	×	27.000	=cubic feet
Miles	×	63360.000	=inches
Miles	×	5280.000	=feet
Miles	×	1760.000	=yards
Avoirdupois ounces	×	0.0625	=pounds
Avoirdupois ounces	×	0.00003125	=tons
Avoirdupois pounds	×	16.000	=ounces
Avoirdupois pounds	×	.01	=hundredweight
Avoirdupois pounds	×	0.0005	=tons
Avoirdupois pounds	×	27.681	=cu. in wat. at 39.2°F.
Avoirdupois tons	×	32000.00	=ounces
Avoirdupois tons	×	2000.00	=pounds
Horsepower	×	746.00	=Watts
Watts	×	0.00134	=horsepower

Cubic feet (of water) (39.1°)	×	62.425	= pounds
Cubic feet (of water) (39.1°)	×	7.48	= U. S. gallons
Cubic feet (of water) (39.1°)	×	6.232	= English gallons
Cubic feet (of water) (39.1°)	×	0.028	= tons
Cubic foot of ice	×	57.2	= pounds
Cubic inches of water (39.1°)	×	0.036024	= pounds
Cubic inches of water (39.1°)	×	0.004329	= U. S. gallons
Cubic inches of water (39.1°)	×	0.003607	= English gallons
Cubic inches of water (39.1°)	×	0.576384	= ounces
Pounds of water	×	27.72	= cubic inches
Pounds of water	×	0.01602	= cubic feet
Pounds of water	×	0.083	= U. S. gallons
Pounds of water	×	0.10	= English gallons
Tons of water	×	268.80	= U. S. gallons
Tons of water	×	224.00	= English gallons
Tons of water	×	35.90	= cubic feet
Ounces of water	×	1.735	= cubic inches

A column of water 1 inch square by 1 foot high weighs 0.434 pounds.

A column of water 1 inch square by 2.31 feet high weighs 1 pound.

Water is at its greatest density at 39.2° F.

Sea water is 1.6 to 1.9 heavier than fresh.

One cubic inch of water makes approximately 1 cubic foot of steam at atmospheric pressure.

27222 cubic feet of steam at atmospheric pressure weighs 1 pound.

Weight of round iron per foot = square of diameter in quarter inches ÷ 6

Weight of flat iron per foot = width × thickness × 10-3.

Weight of flat plates per square foot = 5 pounds for each ⅛-inch thickness.

Weight of chain = diameter squared × 10.7 (approximately.)

Safe load (in pounds) for chains = square of quarter inches in diameter of bar.

Water Factors

U. S. gallons	×	8.33	= pounds
U. S. gallons	×	0.13368	= cubic feet
U. S. gallons	×	231.00	= cubic inches
U. S. gallons	×	0.83	= English gallons
U. S. gallons	×	3.78	= litres
English gallons (Imperial)	×	10	= pounds
English gallons (Imperial)	×	0.16	= cubic feet
English gallons (Imperial)	×	277.274	= cubic inches
English gallons (Imperial)	×	1.2	= U. S. gallons
English gallons (Imperial)	×	4.537	= litres

To find circumference of a circle multiply diameter by 3.1416.

To find diameter of a circle multiply circumference by .3183.

To find area of a circle multiply square of diameter by .7854.

To find surface of a ball multiply square of diameter by 3.1416.

To find side of an equal square multiply diameter by .8862.

To find cubic inches in a ball multiply cube of diameter by .5236.

Doubling the diameter of a pipe increases its capacity four times.

A gallon of water (U. S. standard) weighs 8⅓ lbs. and contains 231 cubic inches.

A cubic foot of water contains 7.48 gallons, 1728 cubic inches, and weighs 62.4 lbs.

To find the pressure in pounds per square inch of a column of water multiply the height of the column in feet by .434.

A standard horse power: The evaporation of 30 lbs. of water per hour from a feed-water temperature of 100° F. into steam at 70 lbs. gauge pressure. One horse power is the power required to raise 33,000 lbs. one foot in one minute.

Equals	33,000	foot-pounds	per minute
"	1,980,000	"	" hour

To find the horse-power of an engine multiply the piston speed in feet per minute by the area of the piston in square inches and by the mean effective pressure, then divide by 33,000.

Each nominal horse power in boilers requires one cubic foot of water per hour.

In calculating horse power of tubular boilers, consider 12 square feet of heating surface equal to one nominal horse power.

To find capacity of tanks any size; given dimensions of a cylinder in inches, to find its capacity in U. S. gallons:

Square the diameter, multiply by the length and by .0034.

To approximately ascertain heating surface in tubular boilers multiply ⅔ the circumference of boiler by length of boiler in inches and add to it the area of all the tubes.

When designing boilers the T. S. is specified, the factor of safety, diameter and pressure per square inch are decided upon, and the only quantities remaining unknown are the thickness and the efficiency of the joint.

Let P = pressure of steam in pounds per square inch.
T = thickness of plate in shell.
E = efficiency of joints in shell.
D = diameter of shell.
S_1 = ultimate strength of material.
F = factor of safety.

Solving the equation $\frac{D \times P \times F}{2\, S_1} = T \times E$

$$\text{or } \frac{D \times P \times F}{2\, S_1 \times E} = T$$

Pressure allowable for concaved heads of boilers: Multiply the pressure per square inch allowable for bumped heads attached to boilers or drums convexly by the constant .6, and the product will give the pressure per square inch allowable in concaved heads.—*U. S. Gov. Rule II, Par. 12.*

To find the amount of air that can be produced by different size air cylinders: Find the area of the cylinder and multiply that by the stroke; then multiply result by 2 if it is a Straight Line Compressor; by 4 if a Duplex Compressor; or by 2 if Compound Duplex Compressor. Divide this result by 1728, which will give amount of air per stroke and then multiply by number of strokes per minute.

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Y

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